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A MODEL FOR ANALYZING AIRCRAFT MAINTENANCE MAN-HOUR COSTS AND THE IMPACT OF EXPERT SYSTEMS

by

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June 1995

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The process for determining the impact on direct labor maintenance man-hours by applying expert systems to diagnosis aircraft discrepancies is addressed. Based on field interviews with Navy enlisted maintenance technicians and technical representatives, average direct labor maintenance man-hour cost savings are projected by applying expert systems.

The interviews contained quantitative and qualitative information to formulate the potential cost savings. To enhance future investigative efforts, an empirical model is developed by the authors. The model categorizes failed components based on their average fault isolation times or beyond economical repair status of the organization. Based upon the categorization of components, the potential maintenance man-hours cost savings can be projected when applying expert systems to help resolve difficult and complex aircraft discrepancies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AEW	Airborne Early Warning
AE1	Aviation Electrician's Mate First Class
AIMD	Aircraft Intermediate Maintenance Department
ASW	Anti-Submarine Warfare
AT1	Aviation Electronics Technician First Class
AT2	Aviation Electronics Technician Second Class
AW	Aviation Warfare
AZ1	Aviation Maintenance Administrationman First Class
BCM	Beyond the Capability of Maintenance
CAIA	Center for Artificial Intelligence Applications
CASS	Consolidated Automated Support System
CETS	Contractor Engineering and Technical Services
CND	Cannot Duplicate
CONUS	Continental United States
DD	Defense Department
D-LEVEL	Depot Level
DOD	Department Of Defense
DPRO	Defense Plant Representative Office
DSF	Data Services Facility
EMT	Elapsed Maintenance Time
ENSAC	ENgine Structural Analysis Consultant

EOTS	Electro-Optical Test Set
ETS	Engineering and Technical Services
FCMDS	Flight Control Maintenance Diagnostic System
FCS	Fire Control System
FFG	Guided Missile Frigate
FLIR	Forward-Looking Infrared Radar
FY	Fiscal Year
HR	Hour
HRS	Hours
IBM	International Business Machines
ICS	Intercommunication Systems
IEEE	Institute of Electrical and Electronic Engineers
I-LEVEL	Intermediate Level
LCDR	Lieutenant Commander
LT	Lieutenant
MAD	Magnetic Anomaly Detection
MAF	Maintenance Action Form
MDS	Maintenance Data System
METER	Metrology Equipment Recall Card
MIM	Maintenance Instruction Manual
ML1	Maintenance Level 1
ML2	Maintenance Level 2

MMH	Maintenance Man-Hour
Mod 2	Modification 2
MRC	Maintenance Requirement Card
NADEP	Naval Aviation Depot
NAESU	Naval Aviation Engineering Service Unit
NALDA	Naval Logistics Data Analysis
NAMO	Naval Aviation Maintenance Office
NAMP	Naval Aviation Maintenance Program
NAMSO	Naval Aviation Maintenance Support Office
NARF	Naval Aviation Rework Facility
NAS	Naval Air Station
NATSF	Naval Air Technical Services Facility
NAVAIRSYSCOM	Naval Air Systems Command
NAVCOMPT	Naval Comptroller
NAVFLIR	Naval Aircraft Flight Record
NDI	Non-Destructive Inspection
NETS	Navy Engineering and Technical Services
NMC	Not Mission Capable
NMCM	Not Mission Capable Maintenance
NMCS	Not Mission Capable Supply
NPS	Naval Postgraduate School
OCT	October

O-LEVEL	Organizational Level
OPNAVINST	Office of the Chief of Naval Operations Instruction
RADM	Rear Admiral
RETOK	Retest OK
RFI	Ready for Issue
RNAV	Radar Navigation
SE	Support Equipment
SEP	September
SRA	Shop Replaceable Assembly
TAD	Temporary Additional Duty
TD	Technical Directive
TEAMS	Technical Expert Aircraft Maintenance System
UHF	Ultra-High Frequency
USAF	United States Air Force
VAST	Vesatile Avionics Shop Test
VIDS/MAF	Visual Information Display System/Maintenance Action Form
WRA	Weapons Replaceable Assembly
WUC	Work Unit Code
3M	Maintenance and Material Management

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I. INTRODUCTION

Naval aviation maintenance managers in the post-cold war period are responsible for ensuring aircraft maintenance continues to be performed in a safe, efficient manner. This proves to be a continual challenge considering declining Department of Defense (DOD) resources, the decommissioning of aircraft squadrons and a general reduction in forces.

Maintenance managers must continually seek new ways to optimize scarce resources and assist technicians in maintaining aircraft systems at the organizational, intermediate and depot maintenance levels.

Research at the Naval Postgraduate School (NPS) demonstrated that using expert system software to troubleshoot the primary fire control system of guided missile frigates (FFGs) offered significant savings in support parts and marked improvement in operational readiness.[1]

The commercial and defense aerospace field has also developed expert systems (Prerau, 1990). This thesis looks at one factor for evaluating the employment of expert systems for meeting future challenges in the field of Naval aviation maintenance.

A. OBJECTIVES

The primary objective of this research is to determine a process for determining the impact on direct labor maintenance man-hours (MMHs) of applying expert systems to assist in diagnosis of aircraft discrepancies.

The secondary objective of this research is to identify direct labor MMH costs associated with the *Hornet*, *Hawkeye* and *Viking* aircraft at the organizational and intermediate maintenance levels.

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[1]A developmental expert system, designated as the MK 92 Modification 2 (Mod 2) Fire Control System (FCS) Maintenance Advisor Expert System, is used to troubleshoot the fire control system of the U.S. Navy's Oliver Hazard Perry class of FFGs. (Powell, 1993)

The following primary research question is addressed:

- Can a model be developed to derive the potential direct labor MMH cost savings by using expert systems to assist fault isolation of *Hornet*, *Hawkeye* and *Viking* systems/components?

Secondary research questions include:

- What are some of the potential benefits of using expert systems in the Naval aviation maintenance field?

- What are the top five component MMH consumers at the organizational maintenance level for the *Hornet*, *Hawkeye* and *Viking* aircraft during Fiscal Year 1994?

- What are the top five component MMH consumers at the intermediate maintenance level for the *Hornet*, *Hawkeye* and *Viking* aircraft during Fiscal Year 1994?

- What are the direct labor MMH costs, using conventional fault isolation methods to identify failed components, for the three aircraft during Fiscal Year 1994?

B. SCOPE, LIMITATIONS AND ASSUMPTIONS

This study is limited to potential economic consideration of the use of expert systems to reduce direct labor MMHs required to fault isolate *Hornet*, *Hawkeye* and *Viking* components. Because of the long lead time requirements to obtain usable data, the study does not address the economic feasibility of potentially using expert systems to resolve aircraft readiness degraders or A-799 (no defect, malfunction could not be duplicated, item checks good) issues. Study assumptions are stated within the context that they occur.

C. RESEARCH METHODOLOGY

Data collection for this thesis was conducted on-site and through telephone conversations. Organizations and personnel that supported this research included: the

Naval Aviation Maintenance Office (NAMO, Code 352-1); the Aircraft Intermediate Maintenance Department (AIMD), Naval Air Station (NAS) Lemoore, California; the Naval Aviation Engineering Service Unit (NAESU) Detachment Lemoore, NAS Lemoore, California; Antisubmarine Squadron 33 (VS-33); AIMD NAS North Island, California; AIMD NAS Miramar, California; McDonnell Douglas Corporation, Saint Louis, Missouri; and a group of Aerospace Maintenance Duty Officers assigned to the NPS, Monterey, California.

Description of Naval aviation maintenance programs, procedures and terms are based on applicable aviation maintenance instructions and the authors' knowledge and experience gained while collectively serving at four separate Naval aircraft squadrons and two AIMDs.

An in-depth review of commercial and military aviation maintenance literature was conducted. In addition an independent self study was performed by the authors to gain a working knowledge about expert systems.

D. THESIS ORGANIZATION

The remaining chapters of this thesis are organized as follows:

II. <u>OVERVIEW OF NAVAL AVIATION MAINTENANCE</u>. The Naval Aviation Maintenance Program and its controlling document, Office of the Chief of Naval Operations Instruction (OPNAVINST 4790.2E, Volumes I-VI), are briefly discussed. An overview of organizational, intermediate and depot maintenance levels is presented and their specific functions are outlined. Also, the Maintenance Data System (MDS) is reviewed, specific Naval aviation maintenance terms are explained and Navy/contractor engineering and technical services are discussed.

III. <u>F/A-18C, E-2C AND S-3B DIRECT LABOR MAINTENANCE MAN-HOUR COSTS</u>. For each of the identified aircraft, the top five component MMH consumers at the organizational and intermediate maintenance levels are listed. The common causes of failure, MMHs expended using conventional fault isolation methods and a direct labor

MMH cost associated with the failed components are identified. The chapter data is for the time frame October 1993 to September 1994.

IV. EXPERT SYSTEMS OVERVIEW. An overview of expert systems is given that includes how expert systems differ from conventional computer programs, the two main system components and their related functions, and the basic steps of how to develop such systems. Commercial and military applications of expert systems are discussed. Included are three specific aviation maintenance uses and the benefits realized from this advanced technology.

V. MAINTENANCE MAN-HOUR COST SAVINGS USING EXPERT SYSTEMS. The concept of using expert systems to help fault isolate F/A-18C, E-2C and S-3B weapon systems is introduced. Based on interviews with Navy enlisted maintenance technicians and technical representatives, average direct labor MMH cost savings are projected from using expert systems. In order to better quantify potential direct labor MMH cost savings benefits from the application of expert systems, an empirical model is developed by the authors.

VI. RESEARCH QUESTIONS AND ANSWERS/CONCLUSIONS/LESSONS LEARNED/RECOMMENDATIONS. A summary of research findings and recommendations are provided. This includes lessons learned and other potential areas to investigate expert systems usage in the field of Naval aviation maintenance.

II. OVERVIEW OF NAVAL AVIATION MAINTENANCE

The purpose of this section is to inform readers not aware of the Naval aviation maintenance process of applicable terms used throughout this study. The high tempo and operational demands of Naval aviation require scheduled and unscheduled aircraft maintenance critical to safe and successful operations. The training and expertise of the technicians and controllers charged with maintaining the aircraft systems is a significant factor in the success or failure of the organization.

The guiding document for Naval Aviation Maintenance is the Office of the Chief of Naval Operations Instruction (OPNAVINST) 4790.2 Series, known as the Naval Aviation Maintenance Program (NAMP). The NAMP presents maintenance policies, procedures and responsibilities for all levels of maintenance throughout Naval aviation. It is the basic document and authority governing management of all Naval aviation maintenance. (OPNAVINST 4790.2E, Volume I)

The NAMP consists of six interrelated volumes. Volume I is primarily introductory, providing concepts, organizational layout, guidance for using the NAMP, Marine Corps maintenance organization, contract maintenance, definitions and change submission procedures. Volume II deals with organizational level maintenance, Volume III with intermediate level maintenance and Volume IV with depot level maintenance. Volume V is concerned with the maintenance data systems, and Volume VI with maintenance data processing requirements. Each of these maintenance levels and categories is explained in the following sections.

A. ORGANIZATIONAL LEVEL (O-LEVEL) MAINTENANCE

Organizational level maintenance is most commonly associated with squadron maintenance. These organizations are the custodians and users of the actual weapons system (i.e., aircraft). Functions and assignment of responsibilities are specifically delineated for all areas of the maintenance activity. Maintenance at the O-level consists primarily of rapid fault isolation and removal/replacement of weapons system components at the operational site. Routine scheduled maintenance and inspections (including painting, corrosion control/treatment and aircraft launch/recovery) are part of O-level maintenance. The NAMP states:

> When removal and replacement of components from a weapons system is required, using only O-level test equipment and hand tools, the maintenance function is O-level. (OPNAVINST 4790.2E, Volume II)

Limited overlap between O-level and intermediate maintenance (I-level) functions are allowed only with justification. It warrants specific approval from the Naval Air Systems Command (NAVAIRSYSCOM).

O-level is considered the most basic level of maintenance logistically, requiring the "least-skilled personnel" (Blanchard, 1992). In practice, squadron level maintenance involves rapid diagnosis and high tempo, dynamic responses to aircraft discrepancies.

At the O-level, tools and test equipment are largely portable. They are designed for deployments and detachments, which are the normal course of operations for an organizational maintenance activity. Organizational maintenance requirements are designed to facilitate the dynamic requirements of fault isolation and repair of components to enhance readiness and mobility.

B. INTERMEDIATE LEVEL (I-LEVEL) MAINTENANCE

Faulty components that have been removed from the aircraft by the O-level maintenance activity are normally beyond the repair capability of that activity. In such cases, a squadron receives a Ready For Issue (RFI) component for reinstallation from the supporting supply department. The faulty component is turned-in/forwarded to the AIMD for repair.

AIMDs are the primary source for maintaining the required level of organizational activity repairable spare parts inventory for the supply department. They are autonomous, independent repair facilities charged with the long-term sustainability of deployed forces. They may be either situated ashore (shore based) or afloat (seagoing). A typical AIMD provides repair facilities for several squadrons and a wide variety of aircraft (fixed wing, rotary wing, jets, propellers).

Shore based AIMDs normally provide repair capability for all the types of aircraft where the AIMD is located. As with O-level repair, some overlap with O-level or depot level (D-level) maintenance is allowed as long as justification and specific approval is received from NAVAIRSYSCOM.

The repair facilities at I-level are much more in-depth than those at the O-level. Specialized repair and test bench equipment are available for avionics, electrical, hydraulics, environmental/egress, power plants and support equipment systems. Test equipment calibration labs and Non-Destructive Inspection (NDI) equipment is also available. In addition airframe welding, composite and conventional airframe repair, plating, painting and corrosion control/treatment capabilities are available.

Repairs are accomplished by technicians specifically trained in I-level repair techniques. As a result of the scope and depth of repairs undertaken, AIMDs are normally much larger organizations than their O-level squadron counterparts. Their role is continually expanding due to their necessary independence resulting from the geographic and technological scope of operations they support.

C. DEPOT LEVEL (D-LEVEL) MAINTENANCE

The final level of aircraft maintenance is at the depot level. D-level maintenance functions include three general categories: rework, manufacture and support services. In addition, depots perform special structural inspections and in-service engineering functions.

Rework is comprised of maintenance and modification. It includes restoration, rebuilding, reclamation, refurbishment, overhaul, repair, replacement, adjustment, servicing, inspection, calibration and testing. Changes and improvements to design through alterations, conversions, engineering changes and modernizations are also performed. (OPNAVINST 4790.2E, Volume IV)

Manufacture involves the manufacture of items and component parts otherwise not available. Support service functions include professional engineering, technology and calibration services. (OPNAVINST 4790.2E, Volume IV)

The structure and composition of the depot level work force is dramatically different than either the organizational or intermediate level. The technicians are almost exclusively civilian, with very few military members involved. Military officers primarily serve in executive and administrative roles. The recent downsizing in defense has seen a reduction in the number of depots.

Naval Aviation Depots are officially known as "NADEPs." NADEPs have the capability to perform rework or complete overhaul on aircraft to extend the aircraft's active service life. The maintenance tasks at NADEPs are much more in-depth and time consuming than either organizational or intermediate maintenance activities. Depot level maintenance often requires the actual transfer of aircraft custody, both physically and administratively, from an operational organization to a depot activity.

D. MAINTENANCE DATA SYSTEM

The Maintenance Data System (MDS) is part of the Navy's Maintenance and Material Management (3M) System and provides the data input to the NAMP. MDS furnishes statistical data products which serve as management tools for efficient and economical maintenance management. MDS deals with equipment maintainability and reliability, equipment configuration (including alteration and technical directive (TD) status), equipment mission capability and utilization, material usage, material non-availability, maintenance/ material processing times and weapon systems/maintenance material costing. (OPNAVINST 4790.2E, Volume V)

MDS requires command attention, support and use since MDS products are only as good as the input information. The system is designed so that each worker, when performing a job, converts a narrative description of the job into codes. The information is entered on standard forms or source documents. (OPNAVINST 4790.2E, Volume V)

Source documents are collected and transmitted to a data services facility (DSF) and converted to machine records which produce periodic reports. These reports provide assistance in planning and directing maintenance. The machine records are then forwarded to the Naval Aviation Maintenance Support Office (NAMSO). (OPNAVINST 4790.2E, Volume V)

A number of senior maintenance executives, the authors and many technicians feel the information available from MDS is not perfect and has inherent limitations. Demanding flight schedules and the paperwork burdens of MDS do not mix well with tired maintenance personnel and flight deck operations. The primary goals of maintenance personnel are related to aircraft readiness, sortie completion, and safety; not with detailed data collection.

Data for this thesis was obtained from the Naval Logistics Data Analysis (NALDA) facility in Patuxent River, Maryland. NALDA is a management information system for aviation logistics management and technical decision support. Analysis capability is provided through interactive query and batch processing from remote terminals. (OPNAVINST 4790.2E, Volume V) NPS is not a remote terminal site.

E. NAVAL AVIATION MAINTENANCE TERMS

Since the following terms are used throughout this thesis, they are explained to acquaint readers with language used in the Naval aviation maintenance field and to facilitate the understanding of this study.

1. System

A system includes related facilities, items, material, services and personnel such that it can be considered a self-sufficient item in its intended operation. (OPNAVINST 4790.2E, Volume V) Examples of a complete system are an aircraft landing gear system, integrated flight control system or radar navigation system.

2. Subsystem

A combination of two or more pieces of equipment, generally separated in operation and such other parts necessary to perform an operational function or functions. (OPNAVINST 4790.2E, Volume V) Examples include a port main landing gear (subsystem) of an aircraft landing gear system or a rudder control system (subsystem) of an integrated flight control system.

3. Component

A number of parts joined together to perform a specific function. This applies to items that cannot be further disassembled for test or repair without requiring shop facilities. (OPNAVINST 4790.2E, Volume V) Examples include a mainmount or an actuator.

4. Weapons Replaceable Assembly (WRA)

A generic term which includes all replaceable packages of avionic equipment, pods or systems in an aircraft weapons system, with the exception of cables, mounts, fuse boxes, or circuit breakers. A WRA is composed of shop replaceable assemblies (SRAs). (OPNAVINST 4790.2E, Volume V)

5. Shop Replaceable Assembly (SRA)

A generic term which includes all the packages within a WRA, including the chassis and wiring for a unit. SRA is a term usually associated with intermediate level maintenance. (OPNAVINST 4790.2E, Volume V)

6. Work Unit Code (WUC)

The WUC is a one, three, five, or seven character numeric or alpha/numeric code. It identifies a system, subsystem, or part of an end item. These codes are published in WUC manuals for end items in three major categories: (1) Type/Model/Series for aircraft, drones and missiles; (2) aircraft tactical trainers, and (3) aeronautical support equipment (SE). The WUC manuals are used to code maintenance actions on end items and components. The system code consists of the first two positions of the WUC and identifies the system within the aircraft/equipment. (OPNAVINST 4790.2E, Volume V)

7. Malfunction Description Code

A three-character numeric or alphanumeric code used to describe the malfunction occurring on or in an item identified by a WUC. (OPNAVINST 4790.2E, Volume V)

8. Maintenance Man-Hours (MMHs)

Maintenance man-hours are the total accumulated direct labor hours expended in performing a maintenance action. Direct maintenance man-hours are man-hours expended by assigned personnel to complete work. This includes the functions of preparation, inspection, disassembly, fault isolation, adjustment, replacement or reassembly of parts and calibration/tests required in restoring the item to a serviceable status.

MMHs also include checking out and returning tools, looking up part numbers in illustrated parts breakdown manuals, transmitting required information to supply points and completing associated documentation. (OPNAVINST 4790.2E, Volume V)

9. Elapsed Maintenance Time (EMT)

EMT is defined as the actual clock time that maintenance was being performed on a job. EMT does not include cure time, charging time, or leak tests when conducted without maintenance personnel actually monitoring the work. Although EMT is directly related to job man-hours, it is not to be confused with total man-hours required to complete a job. For example, if five men complete a job in 2.0 hours of continuous work, the EMT = 2.0 hours and total man-hours = 10.0. (OPNAVINST 4790.2E, Volume V)

10. Not Mission Capable (NMC)

The material condition of an aircraft or training device, indicating that it is not capable of performing any of its missions. It is further subdivided as the sum of Not Mission Capable Maintenance (NMCM) and Not Mission Capable Supply (NMCS). (OPNAVINST 4790.2E, Volume V)

11. Not Mission Capable Maintenance (NMCM)

The material condition of an aircraft or training device, indicating that it is not capable of performing any of its missions because of O-level or I-level maintenance requirements. (OPNAVINST 4790.2E, Volume V)

12. Not Mission Capable Supply (NMCS)

The material condition of an aircraft or training device, indicating that it is not capable of performing any of its missions because the maintenance required to fix or clear the discrepancy cannot continue due to a supply shortage. (OPNAVINST 4790.2E, Volume V)

13. A-799

In order to determine the causes of aircraft discrepancies, rapid diagnostics must be performed at the organizational level, often in the hectic environment of aircraft carrier flight deck operations. This frequently requires the removal of an aircraft component which is sent to the afloat AIMD for repair.

In the event that AIMD is unable to find fault with the component, it is returned to Ready for Issue (RFI) status after a thorough test and check. When such a component is returned with no defect found, the item is considered A-799.

14. Maintenance Instruction Manual (MIM)

A manual containing instructions for organizational and intermediate maintenance and servicing of a specific model aircraft. It identifies each maintenance task to the responsible maintenance level.

F. ENGINEERING AND TECHNICAL SERVICES, NAVY (NETS) AND CONTRACTOR (CETS)

NETS and CETS support services are composed of technical experts specializing in various aircraft weapons systems and test/repair facilities. Contractors supply employee CETS personnel (McDonnell Douglas, Grumman, Lockheed). NETS personnel are controlled by the Naval Aviation Engineering Service Unit (NAESU).

NAESU is a field activity of NAVAIRSYSCOM and reports directly to the Assistant Commander for Logistics and Fleet Support. NAESU head-quarters is located at the Naval Base in Philadelphia, Pennsylvania.

NAESU's mission is to provide field engineering technical assistance and instruction to Naval aviation activities in the installation, maintenance repair and operation of aviation systems and equipment. (NAESU 50th Anniversary Brochure)

G. SUMMARY

This chapter provided an overview of the Naval aviation maintenance program. The topics covered were a breakdown of the Naval aviation maintenance organization, general/specific responsibilities, and the inter-relationships between respective organizational areas. Selected terms were defined that are used throughout the body of this research. Chapter III provides a snapshot view of the direct labor MMH costs, without using expert systems, to fault isolate aircraft systems or components.

III. F/A-18C, E-2C AND S-3B DIRECT LABOR MAINTENANCE MAN-HOUR COSTS

Maintenance managers have gauges to measure the efficiency, effectiveness and economic performance levels of an organization. Direct labor maintenance man-hours (MMHs) is one gauge used in the aviation maintenance field to measure performance levels. When managers know the number of MMHs consumed, plus the rates of labor to perform specific maintenance actions, the organization's direct labor cost can be determined.

This chapter briefly describes the F/A-18C *Hornet*, E-2C *Hawkeye* and S-3B *Viking* aircraft and their roles. For each of the aircraft, the top five component maintenance man-hour (MMH) consumers at the organizational and intermediate maintenance levels are presented and evaluated. A direct labor MMH cost per hour is calculated and combined with the selected weapon system's MMHs. This information gives a snapshot view of how much it directly costs to support the aircraft maintenance effort.

The direct labor MMH costs are based solely on using conventional fault isolation methods.[2] No use of an expert system is considered. All direct labor MMH costs will be referred to as MMH costs throughout the remainder of this study. Also, all MMH costs were incurred from October 1993 to September 1994. Therefore, the costs are presented in Fiscal Year (FY) 1994 dollars.

A. MMH COST PER HOUR

On the basis of the authors' 32 years of accumulated experience in aviation maintenance, a decision was made to use the E-5 paygrade to calculate an hourly labor cost to perform aircraft maintenance. This decision was based on the following:

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[2]Conventional fault isolation methods consist of technicians using maintenance instruction manuals (MIMs), experience, suggestions of counterparts, and any available resource materials and/or assistance from technical representatives to solve aircraft maintenance problems.

- E-7 and above personnel perform aviation maintenance manager related functions and do not perform "hands-on" maintenance tasks unless absolutely necessary.

- E-6 personnel supervise the vital functions of their work centers and maintain constant communications with maintenance control at the organizational maintenance level and production control at the intermediate maintenance level.

- E-5 personnel perform the vast majority of fault isolation and repair/replace maintenance actions. They are technically competent, have completed their training tracks and are not required to perform temporary additional duty (TAD) functions.

- E-4 and below personnel do not perform the majority of fault isolation and repair/replace maintenance actions. Their weapon system's learning curve rate is high as compared to other technicians. Also, they have not completed their training tracks and are eligible to perform TAD functions.

- Maintenance requirement cards (MRCs) delineate specific maintenance tasks for each rating/paygrade. E-5 is an acceptable average.

The composite hourly labor rate for an E-5 maintenance technician is $16.28, in FY 1992 dollars, as provided in Naval Comptroller (NAVCOMPT) Notice 7041 dated 1992. The composite rate does not factor in compensation for leave and holiday accrual, medical benefits and accrual of other personnel support costs.

An hourly labor rate of $16.28 must be accelerated by: (1) a factor of 114 percent to compensate for leave and holiday accrual, and (2) a factor of 118 percent to compensate for accrual of other personnel support costs (NAVCOMPT Notice 7041, p. 5-95). The composite hourly labor rate is therefore $21.90 for an E-5 maintenance technician in FY 1992 dollars.

Since this study uses FY 1994 weapons system's data, the FY 1992 $21.90 rate is inflated by a factor of 105.89 percent. This establishes an E-5 composite hourly labor rate of $23.19 in FY 1994 dollars (Office of Management and Budget, 1994). The E-5 composite hourly rate of $23.19 is used to in calculate MMH costs and average MMH cost savings. Table I summarizes this process. Following the table, a discussion of each aircraft and breakout of the top component MMH consumers is made.

$16.28	Composite hourly labor rate for an E-5 in FY 1992 dollars
x 114%	Accelerated compensation factor for leave and holiday accrual
$18.56	Composite hourly labor rate for an E-5, in FY 1992 dollars, after applying the leave and holiday acceleration factor
x 118%	Accelerated composition factor for accrual of other personnel support costs
$21.90	Composite hourly labor rate for an E-5, in FY 1992 dollars, after applying the accrual of other personnel support costs acceleration factor
x 105.89%	Inflation factor to convert FY 1992 dollars to FY 1994 dollars
$23.19	E-5 composite hourly labor rate in FY 1994 dollars

Table I. Acceleration Schedule for Converting an E-5 Composite Hourly Labor Rate from FY 1992 to FY 1994 Dollars

B. F/A-18C *HORNET*

The F/A-18C *Hornet* is a dual engine, single-seat aircraft that performs the strike-fighter role in the Navy and Marine Corps. The *Hornet* is highly maneuverable, is capable of Mach plus speed and armed with a 20-millimeter cannon. Wingtip positions, three fuselage stations and four wing stations for weapons and sensor/guidance pods, enable the aircraft to perform its role merely by changing weapon racks. (Polmar, 1987) As of September 30, 1994, there were 333 F/A-18C aircraft in the Navy/Marine Corps inventory.

Three questions are often asked by aviation maintenance managers: (1) which components fail, (2) what causes the components to fail, and (3) what are the number of MMHs consumed in fault isolation and repair/ replacement of failed components.

Once these questions are asked, aviation maintenance managers are better able to analyze aircraft maintenance problems and provide viable solutions to problems.

Based on the previous three questions, a short discussion on the top five O- and I-level component MMH consumers, the causes of failure, and the associated costs for the three aircraft follows.

1. Top Five F/A-18C Component MMH Consumers at the O-Level

Table II lists the top five component MMH consumers for the period October 1993 to September 1994. The number one *Hornet* MMH consumer was the SUU63/A aircraft pylon. Corrosion was the leading cause of failure; 3,082.6 MMHs were consumed fixing pylon failures. The second largest MMH consumer was the LAU7/A guided missile launcher. The leading cause of failure, once again, was corrosion; 2,445.9 MMHs were consumed by launcher failures.

The BRU32/A aircraft ejector rack was the third leading consumer of MMHs. Corrosion was again the leading cause of failure; 1,761.6 MMHs were consumed by ejector rack failures. Aileron installation was the fourth leading MMH consumer at the O-level. The number one cause of failure was corrosion. Aileron failures accounted for 587.0 MMHs.

The main landing gear mechanical installation completed the list of top five component MMH consumers. Corrosion was the main cause of failure; 251.5 MMHs were consumed. Additional weapon systems data can be found in Appendix A.

2. Top Five F/A-18C Component MMH Consumers at the I-Level

As listed in Table III, the APG65[2] radar transmitter, APG65 radar receiver exciter and APG65 antenna consumed the majority of MMHs. These three components are subsystem components of the weapons control system. They are identified by a WUC 74 two-digit system code.

[2]Weapon systems are categorized by equipment indicator letters. These letters indicate where the equipment is installed, what type of equipment it is and what function(s) the equipment performs. For example, the APG code is broken down as follows: A indicates equipment installed and operated in aircraft, P indicates radar equipment and G indicates fire control or search directing equipment.

Component	Cause of Malfunction	Malfunction Description Code	Number of Failures	MMH
SUU63/A Aircraft Pylon	Corroded Punctured Nicked/Chipped Cracked/Crazed Stripped/Worn	170 070 425 190 020	1,008 116 84 47 36	3,082.6
LAU7/A Guided Missile Launcher	Corroded Punctured Nicked/Chipped Stripped/Worn Broken Wire	170 070 425 020 160	818 215 130 67 50	2,445.9
BRU32/A Aircraft Ejector Bomb Rack	Corroded Does Not Lock Broken Wire Stripped/Worn Adjustment	170 932 160 020 127	899 38 34 31 30	1,761.6
Aileron Installation	Corroded Punctured Cracked/Crazed Nicked/Chipped Stripped/Worn	170 070 190 425 020	54 15 9 9 7	587.0
Main Landing Gear Mechanical Installation	Corroded Nicked/Chipped Stripped/Worn Punctured Rigging	170 425 020 070 128	63 9 6 6 2	251.4

Table II. Top Five F/A-18C Component MMH Consumers at the O-Level (FY 1994)

Component	Cause of Malfunction	Malfunction Description Code	Number of Failures	MMH
APG65 Radar Transmitter	Fails Tests Broken Wire Punctured Voltage Failure	290 160 070 169 374	242 229 18 15 10	11,493.5
APG65 Radar Receiver Exciter	Broken Wire Adjustment Fails Tests Punctured Voltage	160 127 290 070 169	163 158 150 9 5	10,579.8
APG65 Antenna	Fails Tests Adjustment Broken Wire Punctured Scheduled Maintenance	290 127 160 070 804	258 229 58 17 8	7,898.7
ASW44 Pitch-Roll-Yaw Computer	Broken Wire Fails Tests Adjustment Voltage Wrong Logic	160 290 127 169 447	275 136 10 7 6	5,570.3
Radio Receiver/ Transmitter	Adjustment No Output Punctured Broken Wire Voltage	127 255 070 160 169	309 175 8 3 3	4,819.9

Table III. Top Five F/A-18C Component MMH Consumers at the I-Level (FY 1994)

Since the components are part of a common system, their data was aggregated together. Fails diagnostic/automatic tests and broken wire/defective contact/connection were the leading causes of failure. The APG65 components accounted for 29,972.0 MMHs.

The ASW44 pitch-roll-yaw computer was the fourth leading consumer of MMHs. The leading cause of failure was broken wire/defective contact/connection. This type of failure occurred 275 times. The second leading cause of failure was fails diagnostic/automatic tests. It occurred 136 times and MMHs consumed by the ASW44 came to 5,570.3.

The radio receiver/transmitter (WUC 62X21) concluded the list of top five component MMH consumers. The leading cause of failure was adjustment/alignment improper; 4,819.9 MMHs were consumed during FY 1994.

3. F/A-18C MMH Costs

Table IV lists the costs for the O-level and I-level top five component MMH consumers. The total cost for the top five MMH consumers was $1,124,499.33 for *Hornet* maintenance at both levels.

The *Hornet* MMH cost drivers occurred at the intermediate maintenance level. The weapons control system components (WUCs 742G1, 742G2, 742G6) accounted for approximately 62 percent of the total MMH cost. When one factors in the ASW44 pitch-roll-yaw computer and radio receiver/ transmitter failures, the I-level accounted for 83 percent total MMH costs in the F/A-18C.

C. E-2C *HAWKEYE*

The E-2C *Hawkeye* is a carrier-based Airborne Early Warning (AEW) aircraft developed specifically for aircraft carrier operations. The *Hawkeye's* most distinctive feature is a 24-foot diameter, saucer-like radome that houses the ultra high frequency (UHF) radar. The radar gives the aircraft an effective detection range of approximately 240 nautical miles. It has both over land and water capability. More than 250 air targets

Component	WUC	MMH	MMH Cost Per Hour	MMH Costs
O-Level				
SUU63/A Aircraft Pylon	75E51	3,082.6	$23.19	$71,485.49
LAU7/A Guided Missile Launcher	751B6	2,445.9	$23.19	$56,720.42
BRU32/A Aircraft Ejector Bomb Rack	754CD	1,761.6	$23.19	$40,851.50
Aileron Installation	14211	587.0	$23.19	$13,612.53
Main Landing Gear Mechanical Installation	13C11	251.4	$23.19	$5,829.97
I-Level				
APG65 Radar Transmitter	742G1	11,493.5	$23.19	$266,534.27
APG65 Radar Receiver Exciter	742G2	10,579.8	$23.19	$245,345.56
APG65 Antenna	742G6	7,898.7	$23.19	$183,170.85
ASW44 Pitch-Roll-Yaw Computer	57D91	5,570.3	$23.19	$129,175.26
Radio Receiver/ Transmitter	62X21	4,819.9	$23.19	$111,773.48
Total MMH Cost				$1,124,499.33

Table IV. F/A-18C *Hornet* MMH Costs (FY 1994)

can be simultaneously tracked and up to 30 interceptors can be controlled. (Polmar, 1987) As of September 30, 1994, there were 123 E-2C aircraft in the Navy inventory.

1. Top Five E-2C Component MMH Consumers at the O-Level

Table V lists the top five component MMH consumers for the period October 1993 to September 1994. The number one *Hawkeye* component MMH consumer was the variable pitch propeller. Corrosion was the primary cause of failure; this was followed closely by internal/external leaking. Propeller failures accounted for 4,808.3 MMHs.

The second leading MMH consumer was the power plant system installation/engine assembly. Corrosion was once again the leading cause of failure. Related failures accounted for 2,716.0 MMHs.

Utility lights consumed the third largest amount of MMHs. Burned out light bulbs/fuses was the leading cause of failure. Utility light failures accounted for 1,639.1 MMHs. The rudder was the fourth leading consumer of MMHs at the O-level. Corrosion was the primary cause of failure. Rudder failures consumed 1,298.7 MMHs.

The O-level's fifth largest MMH consumer was the propeller control assembly. Corrosion, again, was the leading cause of failure. The propeller control assembly consumed 510.7 MMHs.

2. Top Five E-2C Component MMH Consumers at the I-Level

The radar navigation (RNAV) system (WUC 72) had four of the top five component MMH consumers. The components (WUCs 726J2, 726J4, 728E2, 728E1) are part of a common system and the data is therefore aggregated. Table VI and Appendix A have more detailed data. Broken wire/defective contact/connector, adjustment/ alignment improper and "no output" were the leading causes of failure. The RNAV system accounted for 7,383.3 MMHs. The AIC14 intercommunication system (ICS) control was the remaining top five MMH consumer. All five leading causes of failure were closely distributed. The AIC14 accounted for 2,491.9 MMHs.

3. E-2C MMH Costs

The *Hawkeye's* total MMH cost was $483,465.12 for the top five selected weapon systems data. Organizational level MMH cost accounted for approximately 53 percent of the total cost. As documented in Table VII, the variable pitch propeller (WUC 32512) was the major O-level cost driver. It accounted for 23 percent of the total MMH cost.

Component	Cause of Malfunction	Malfunction Description Code	Number of Failures	MMH
Variable Pitch Propeller	Corroded Stripped/Worn Deteriorated Adjustment Out of Balance	170 020 117 127 458	67 62 44 44 40	4,808.3
Power Plant System Install/ Engine Assembly	Corroded Adjustment Contamination Stripped/Worn Leaking	170 127 306 020 381	241 70 70 68 36	2,716.0
Utility Light	Burned Out Bulbs/Fuses Broken Wire Punctured Corroded Internal Failure	080 160 070 170 374	1,060 100 76 31 13	1,639.1
Rudder	Corroded Stripped/Worn Cracked Nicked Punctured	170 020 190 425 070	95 40 32 32 19	1,298.7
Propeller Control Assembly	Corroded Leaking Punctured Fluctuates Adjustment	170 381 070 037 127	14 8 5 4 3	510.7

Table V. Top Five E-2C Component MMH Consumers at the O-Level (FY 1994)

Component	Cause of Malfunction	Malfunction Description Code	Number of Failures	MMH
Azimuth Range Indicator	Adjustment Broken Wire Fails Tests Punctured Internal Failure	127 160 290 070 374	102 85 75 15 4	7,160.5
AIC14 ICS Control	No Output Punctured Broken Wire Adjustment Internal Failure	255 070 160 127 374	77 63 57 31 10	2,491.9
Azimuth Range Indicator	Punctured Broken Wire Adjustment Stuck/Binding Fails Tests	070 160 127 135 290	15 12 7 2 2	202.2
Digital Data Converter	Punctured Broken Wire Internal Failure	070 160 374	7 1 1	17.0
Digital Data Computer	Adjustment	127	1	3.6

Table VI. Top Five E-2C Component MMH Consumers at the I-Level (FY 1994)

Component	WUC	MMH	MMH Cost Per Hour	MMH Costs
O-Level				
Variable Pitch Propeller	32512	4,808.3	$23.19	$111,504.48
Power Plant System Installation/ Engine Assembly	29E10	2,716.0	$23.19	$62,984.04
Utility Light	4422K	1,639.1	$23.19	$38,010.73
Rudder	14121	1,298.7	$23.19	$30,116.85
Propeller Control Assembly	32513	510.7	$23.19	$11,843.13
I-Level				
Azimuth Range Indicator	726J2	7,160.5	$23.19	$166,052.00
AIC14 ICS Control	64184	2,491.9	$23.19	$57,787.16
Azimuth Range Indicator	726J4	202.2	$23.19	$4,689.02
Digital Data Converter	728E2	17.0	$23.19	$394.23
Digital Data Computer	728E1	3.6	$23.19	$83.48
Total MMH Cost				$483,465.12

Table VII. E-2C *Hawkeye* MMH Costs (FY 1994)

Forty-seven percent of the total MMH cost was accumulated at the intermediate maintenance level. The azimuth range indicator (WUC 726J2) was the number one cost driver, accounting for 34 percent of the total cost. The combined I-level cost driver data for WUCs 726J2, 726J4, 728E2 and 728E1 accounted for only 35 percent of the total MMH cost.

D. S-3B *VIKING*

The S-3B *Viking* is a Navy, aircraft carrier deployable, anti-submarine warfare (ASW) aircraft. It has an internal weapons bay and carries an assortment of weapons, including torpedoes. It has two wing pylons capable of carrying Harpoon anti-ship missiles, a variety of bombs, aerial refueling stores that provide an in-flight refueling capability, and general material transport via a blivet. The aircraft's ASW systems include magnetic anomaly detection (MAD), forward-looking infrared radar (FLIR), and sonobuoys in fuselage chutes. (Polmar, 1987) As of September 30, 1994, there were 103 S-3B aircraft in the Navy inventory.

1. Top Five S-3B Component MMH Consumers at the O-Level

Table VIII lists the top five component MMH consumers for the period of October 1993 to September 1994. The ASW33 flight data computer was the number one O-level MMH consumer. Broken wire/defective contact/ connector was the leading cause of failure. This was followed by internal failure of the component. The ASW33 accounted for 2,697.0 MMHs.

The number two item on the MMH consumer list was the switch logic unit. Broken wire/defective contact/connector once again was the leading cause of failure. The switch logic unit accounted for 2,489.4 MMHs. The integrated radio controller consumed the third largest amount of MMHs at the O-Level. Again, broken wire/defective contact/connector was the number one cause of failure. It occurred 310 times and 1,879.4 MMHs were consumed by integrated radio controller failures.

The BRU14 bomb rack assembly placed fourth among MMH consumers. Corrosion was the prime reason for failure. The BRU14 accounted for 877.2 MMHs.

Component	Cause of Malfunction	Malfunction Description Code	Number of Failures	MMH
ASW33 Flight Data Computer	Broken Wire Internal Failure Adjustment Punctured No Output	160 374 127 070 255	559 297 128 55 29	2,697.0
Switch Logic Unit	Broken Wire No Output Fails Tests Internal Failure Corroded	160 255 290 374 170	470 138 82 79 44	2,489.4
Integrated Radio Controller	Broken Wire Burned Out Bulbs/Fuses No Output Internal Failure Punctured	160 080 255 374 070	310 242 80 77 44	1,879.4
BRU14 Bomb Rack Assembly	Corroded Broken Wire Punctured Adjustment Stripped/Worn	170 160 070 127 020	620 68 26 22 9	877.2
Engine Wing Pylon Install/ Assembly	Corroded Punctured Peeled/Ruptured Stripped/Worn Cracked/Crazed	170 070 429 020 190	113 18 17 8 8	425.8

Table VIII. Top Five S-3B Component MMH Consumers at the O-Level (FY 1994)

Fifth on the list of failures was the engine wing pylon installation/assembly. Again, corrosion was the primary cause of failure; 425.8 MMHs were consumed by these failures.

2. Top Five S-3B Component MMH Consumers at the I-Level

The ASW33 flight data computer was the number one consumer of MMHs at the I-level. As listed in Table IX, broken wire/defective contact/connector was the main cause of failure. ASW33 failures accounted for 8,498.2 MMHs.

The switch logic unit was the second leading consumer of MMHs. The main cause of failure was broken wire/defective contact/connector. This type of malfunction occurred 240 times; 6,565.6 MMHs were consumed by switch logic unit failures.

Placing third among MMH consumers was the navigation data converter. Again, the leading cause of failure was broken wire/defective contact/connector. The navigation data converter accounted for 6,292.7 MMHs. The ARC156 radio receiver/transmitter was the fourth leading MMH consumer. Adjustment/alignment was the leading cause of failure. This was followed closely by fails diagnostic/automatic tests. ARC156 failures consumed 5,487.8 MMHs.

Fifth on the I-level's MMH consumer list was wheel/tire assemblies. The leading cause of failure was eddy-current inspection, followed closely by stripped/worn discrepancies. The wheel/tire assemblies accounted for 191.2 MMHs.

3. S-3B MMH Costs

The total MMH cost was $821,025.72 for *Viking* top five MMH consumers for O-level and I-level as listed in Table X. The organizational maintenance level accounted for 24 percent of the total cost. The ASW33 flight data computer was the number one O-level cost driver at $62,543.43.

Intermediate maintenance level repair accounted for 74 percent of the total cost. The ASW33 flight data computer again accounted for $197,073.26 or 24 percent of the total cost. The ASW33 switch logic unit was the second leading cost driver at a cost of $152,256.26. This was followed by the ASW33 navigation data converter at a cost of $145,927.71.

Component	Cause of Malfunction	Malfunction Description Code	Number of Failures	MMH
ASW33 Flight Data Computer	Broken Wire Fails Tests Punctured Internal Failure Adjustment	160 290 070 374 127	283 151 35 4 3	8,498.2
Switch Logic Unit	Broken Wire Fails Tests Adjustment Punctured Internal Failure	160 290 127 070 374	240 102 43 27 10	6,565.6
Navigation Data Converter	Broken Wire Fails Tests Punctured Adjustment Internal Failure	160 290 070 127 374	272 141 15 14 2	6,292.7
ARC156 Radio Receiver/ Transmitter	Adjustment Fails Tests Broken Wire Punctured Corroded	127 290 160 070 170	149 119 116 33 12	5,487.8
Wheel/Tire Assembly	Eddy-Current Inspection Stripped/Worn Tire Leakage Punctured Magnetic Particle Inspection	572 020 781 070 571	6 4 4 3 3	191.2

Table IX. Top Five S-3B Component MMH Consumers at the I-Level (FY 1994)

Component	WUC	MMH	MMH Cost Per Hour	MMH Costs
O-Level				
ASW33 Flight Data Computer	57367	2,697.0	$23.19	$62,543.43
Switch Logic Unit	64354	2,489.4	$23.19	$57,729.19
Integrated Radio Controller	64351	1,879.4	$23.19	$43,583.29
BRU14 Bomb Rack Assembly	754BQ	877.2	$23.19	$20,342.27
Engine Wing Pylon Installation/ Assembly	29Q4H	425.8	$23.19	$9,874.30
I-Level				
ASW33 Flight Data Computer	57367	8,498.2	$23.19	$197,073.26
Switch Logic Unit	64354	6,565.6	$23.19	$152,256.26
Navigation Data Converter	73B62	6,292.7	$23.19	$145,927.71
ARC156 Radio Receiver/ Transmitter	63271	5,487.8	$23.19	$127,262.08
Wheel/Tire Assembly	13A6K	191.2	$23.19	$4,433.93
Total MMH Cost				$821,025.72

Table X. S-3B *Viking* MMH Costs (FY 1994)

E. SUMMARY

This chapter presented the F/A-18C, E-2C and S-3B top five component MMH consumers at the O-level and I-level. The MMH costs to conventionally fault isolate, replace, and repair each of these components were presented in FY 1994 dollars. Chapter

IV presents an overview of expert systems and introduces the readers to expert systems users. Also, the chapter reviews some of the benefits that expert systems provide.

IV. EXPERT SYSTEMS OVERVIEW

Since this thesis attempts to determine if there is a benefit from developing and applying expert systems for selective aircraft maintenance diagnostics, a brief discussion on their characteristics, uses, and benefits is in order.

An expert system is a computer software program that attempts to replicate the knowledge and decision making capability that human experts have acquired. Human experts make decisions, recommendations, and perform tasks. Frequently, experts also train others to do these same tasks or make the same decisions. Expert systems may also be designed to perform such functions. (Bennett, 1983) A human expert is defined as a person who, through training and experience, can perform a task with a degree of skill that is beneficial to capture and distribute. The person filling this role is usually a top-level task performer although sometimes capturing and automating the judgment of even an average decision maker can be beneficial. (Prerau, 1990)

An expert system, like a human expert, often finds it necessary to extract additional information or data from the user by asking questions related to the problem. In many cases the system can also answer questions about why certain information is needed and the reasoning steps used to reach a conclusion or make the recommendations for solving the problem. (Mockler, 1987)

As compared to conventional computer programs, expert systems may be characterized by the following distinct features. They:

1. Make decisions
2. Are based on heuristics[3]
3. Are more flexible
4. Can handle uncertainty

[3]Heuristics are defined as rules of thumb or strategies used to solve problems.

5. Can work with partial information, inconsistencies, or partial beliefs
6. Can provide explanations of results
7. Use symbolic reasoning
8. Are primarily declarative
9. Separate control and knowledge (Prerau,1990)

Expert systems are based primarily on symbolic reasoning about concepts rather than numeric calculations. The systems are programmed using declarative rather than procedural approaches. The programming techniques allow program control to be separated from domain[4] knowledge. The use of declarative knowledge separated from program control often makes expert systems more flexible and easier to revise and update than conventional programs. (Prerau, 1990)

1. Components of an Expert System

Any expert system consists of two components: the knowledge base and the inference engine (Powell, 1993). The knowledge base stores the facts and heuristics of domain experts. It also includes expert techniques on how and when to use these facts and heuristics. The inference engine provides for system control. It applies the expert domain knowledge (which is in the knowledge base) to what is known about the present situation (which is the information in the working memory) to determine new information about the domain. (Prerau, 1990)

2. Developing an Expert System

According to a model developed by Prerau, development of an expert system consists of four elementary steps. The first step is to select a domain for the expert system. Step two is to select one or more recognized domain experts who have credibility in their field of work. The third step is to determine the techniques, knowledge and

[4]Domain is defined as the problem area of interest.

heuristics used by the expert(s) to perform tasks in their domain. The final step is to design and implement a portable computer program that embodies domain expert's techniques, knowledge and heuristics.

This requires the acquisition of the knowledge that the expert has gained through years of experience in a selected domain and the implementation of that knowledge in an expert system computer program. (Prerau, 1990)

A. USERS OF EXPERT SYSTEMS

Expert systems are widely used by private industry and to a lesser degree by military organizations, both domestically and internationally. Automobile, aerospace, engineering, manufacturing and medical applications have been developed.

The following paragraphs provide three specific examples of how expert systems have been employed in the aerospace field.

1. McDonnell Douglas Corporation

Modern combat aircraft are highly complex weapon systems composed of hundreds of black boxes and thousands of wires. This complexity makes it difficult to isolate failures that occur within an aircraft. The difficulty in isolating a failure is magnified when an aircraft has just completed the manufacturing process. (Lischke, 1992)

The Technical Expert Aircraft Maintenance System (TEAMS) is an interactive system that supports the diagnosis of problems on new McDonnell Douglas aircraft. TEAMS is an expert system that provides the aircraft mechanic with the knowledge and experience information needed to successfully repair an aircraft. By helping mechanics make correct repair decisions, TEAMS reduces the aircraft costs by shortening the time needed to deliver the aircraft and reducing the inventory of spare parts required for preparing an aircraft for delivery. TEAMS is being developed for McDonnell Aircraft's Production Programs, including the F-15E and T-45TS. (Lischke, 1992)

2. Center for Artificial Intelligence Applications (CAIA)

Turbine engine design and analysis is a complex engineering process that relies on previous field experience, testing and computer analysis. A prototype system known as ENgine Structural Analysis Consultant (ENSAC) was developed by CAIA to help an inexperienced structural analyst in (1) choosing the appropriate type of engine analysis to perform, (2) choosing what analysis code to use, (3) determining data requirements, and (4) reducing the number of common learning mistakes. (Papp, Braisted and Taylor, 1992)

ENSAC parameter inputs include data from eight engine sections, a variety of engine components, five types of material and operating environmental conditions.

Results of the prototype system suggests that structural analysts were able to increase their productivity. The ENSAC expert system uses: (1) menu-driven displays, (2)is programmed with software that enables analysts to learn in an unaided manner, and (3) uses familiar International Business Machines (IBM) personal computers.

3. United States Air Force (USAF)

F-16 Falcon electronic system's reliability and maintainability have increased since the aircraft's acceptance by the Air Force in the mid-1970s. However, when an electronic system or component fails, many man-hours are expended in troubleshooting, isolating and repairing the discrepancy.

To assist USAF technicians to repair cannot duplicate (CND) and "Retest OK" (RETOK) flight control discrepancies, Honeywell developed the Flight Control Maintenance Diagnostic System (FCMDS) (Schroder, Smith, Bursch and Meisner 1992).

A controlled experiment was conducted at Luke Air Force Base, Arizona, from September 1990 to June 1991. Some technicians used FCMDS and other technicians used technical manuals to isolate and diagnose F-16 CND and RETOK discrepancies. The experimental constraints that were imposed were that technicians had 45 minutes to complete the maintenance actions and the work had to be completed singlehandedly without any outside assistance.

Results of the field test show enhanced levels of performance can be achieved, at all technician levels, by using a computer-aided maintenance system. The average fault isolation time was reduced by 26 percent and diagnostic accuracy was improved by 92 percent over standard flight line practices. (Schroder, Smith, Bursch and Meisner, 1992)

B. BENEFITS OF USING EXPERT SYSTEMS

Some of the benefits that can be realized by using expert systems include: (1) gains in productivity, (2) continuous improvement in quality, (3) improved level of human performance, (4) decreased time to perform on-equipment/off-equipment maintenance, (5) preservation of vital knowledge, and (6) reduction in part inventory level requirements.

The following paragraphs examine specific industrial users that have reaped benefits of using an expert system.

1. Dupont

At Dupont's River Works in Sabine, Texas, technicians are trained to repair computers. Since computers seldom fail, the technicians' skills were lacking in hands-on computer repairs. To increase the technicians' proficiency in repairing computers, Dupont developed an expert system to continuously train technicians and to maintain a real-time database on repair procedures. The company saved $400,000 in the first year it used the expert system and the system paid for itself in three months. (Heizer and Render, 1993)

2. Toyota Motor Company

The computerization and increasing complexity of automobiles, combined with an insufficient number of qualified auto mechanics, proved disastrous for Toyota. Approximately 40 percent of the parts that were removed and replaced were done so unnecessarily and consumers were unhappy. To regain consumers' confidence, Toyota researched and developed an Atrex expert system. Atrex helped mechanics proficiently troubleshoot auto problems, increased their productivity ten fold by reducing the number of troubleshooting hours and most of all--saved Toyota's reputation. (Feigenbaum, McCorduck and Nii, 1989)

C. SUMMARY

This chapter provided a background and overview on expert systems. The following chapter addresses the issue of using expert systems to fault isolate systems/components of three aircraft.

V. MAINTENANCE MAN-HOUR COST SAVINGS USING EXPERT SYSTEMS

This chapter introduces the concept of using expert systems to help fault isolate F/A-18C, E-2C and S-3B weapon systems and/or components. By using expert systems to assist in the fault isolation process, there is a strong possibility that O- and I-level maintenance man-hours (MMHs) could be reduced and MMH cost savings realized.

The chapter first documents the researchers initial attempt to assess the potential savings in MMH using data from the NALDA and interviews with subject matter experts from the three weapon systems. It then lays out an empirical model that was developed. The paradigm can serve as a generic model for any type of aviation weapon system to calculate potential cost savings from using expert systems.

To assist in determining the possibility of MMH cost savings, interviews were conducted with Navy enlisted aircraft maintenance technicians and technical representatives. They were provided information on expert systems, their uses, associated benefits and how this technology could assist in correcting system/component malfunctions.

The maintenance personnel were asked to screen maintenance action forms (MAFs) at their activity, conduct brainstorming sessions with their counterparts, review maintenance procedures and provide relative aircraft maintenance information to the authors.

Because of the limited time allotted to thesis research in the curriculum (a six quarter program) and the fact that this research was not sponsored, thus restricting the amount of travel by the authors, some limitations and assumptions have been made.

Based upon our professional judgment and experience as aircraft maintenance officers, it was assumed (through a limited sample) that the information provided by the technicians and representatives contacted would be similar to a broader fleet-wide response. The information is used throughout this chapter to calculate MMH cost savings and evaluate the potential use of expert systems in the Naval aviation maintenance field.

A. KEY TERMS AND RATES USED TO CALCULATE MMH COST SAVINGS

Key terminology is defined in order to provide the reader with a clear understanding of how MMH cost savings were calculated. The terms defined are: (1) MMHs, (2) fault isolation percentage, (3) pertinency rate, and (4) efficiency rate.

1. MMHs

MMHs are the total accumulated direct labor hours expended in performing a maintenance action. Direct MMHs are man-hours expended by assigned personnel to complete work. This includes the functions of preparation, inspection, disassembly, fault isolation, adjustment, replacement or reassembly of parts and calibration/tests required in restoring an item to a serviceable status.

It also includes such tasks as checking out and returning tools, looking up part numbers in illustrated parts breakdown manuals, transmitting required information to supply points and completing associated documentation. (OPNAVINST 4790.2E, Volume V)

2. Fault Isolation Percentage

Fault isolation time is the total time expended in isolating the primary cause of malfunction. It is a subset of MMHs, and as such, is considered a percentage of MMHs. It has been the experience of the researchers that it is not unusual for fault isolation time to be 50-80 percent of the available MMHs expended.

For example, if 100 MMHs are expended in returning a system/component to a serviceable status, and fault isolation time is 80 MMHs, the fault isolation percentage is 80 percent (80 MMHs divided by 100 MMHs). This is a key point, since in this study the fault isolation percentage is a critical term used to calculate MMH cost savings.

3. Pertinency Rate

The pertinency rate is that portion of aircraft system/component failures to which an expert system would cover the fault isolation process. It includes the fault isolation MMH reduction rate that may be possible through the use of expert systems. Recall that an expert system incorporates documented factual knowledge available to the average technician with the heuristic knowledge of a domain expert. For example, let us say that with factual knowledge, the average technician can correctly fault isolate 70 out of 100 components. The heuristic knowledge of a domain expert will allow an additional 15 components that previously could not be fault isolated to now be correctly diagnosed. Therefore, with an expert system, the average technician could correctly fault isolate 85 out of 100 components. The pertinency rate in this case would then be 85 percent.

4. Efficiency Rate

The efficiency rate is the ability to correctly fault isolate aircraft system/component failures. It encompasses using either conventional methods (as described in Chapter III) or using expert systems.

Supporters of expert systems claim the fault isolation accuracy rate can often be increased up to 92 percent (Schroeder, Smith, Bursch, Meisner, 1992). In other words, an expert system's fault isolation procedures would correctly diagnose a fault nine out of ten times. This is due in part because expert systems often provide instant access to a knowledge base that may store years of aviation maintenance expertise.

An expert system's encapsulated knowledge can enable average technicians to rapidly resolve complex aircraft maintenance problems. Some would argue it would be overly optimistic to initially expect the fault isolation accuracy rate to reach the maximum of 92 percent (cited by Schroeder, et al), for a newly developed expert system. System accuracy would improve over time. Using prudent, but realistic figures to demonstrate MMH cost savings, the authors chose efficiency rates of 70 and 90 percent to apply to the examples in this chapter. Seventy percent on the low side was a realistic figure. After all, if one assumed a rate of 50 percent (only every other time would the expert system correctly fault isolate), it is unlikely that technicians would use such a system for long.

B. OVERVIEW ON CALCULATING AVERAGE MMH COST SAVINGS

For the aircraft systems and components involved in deriving average MMH cost savings, the same steps were used to calculate the cost savings at the O- and I-levels. The average MMH cost saving differences were due to differences between aircraft MMHs, fault isolation percentages, and pertinency rates.

As previously stated, MMHs were extracted from the NALDA database for the time frame October 1993 to September 1994. Fault isolation percentages and pertinency rates were provided by the previously mentioned technicians and technical representatives. The chosen efficiency rates of 70 and 90 percent remain constant throughout this chapter to compute average MMH cost savings.

Calculating Average MMH Cost Savings

There are four simple steps in calculating the average MMH cost savings listed in the tables. They are:

- MMHs expended on a failed component multiplied by the applicable fault isolation percentage. This provides the average fault isolation man-hours.
- The average fault isolation man-hours are then multiplied by the applicable pertinency rate to derive the average pertinent man-hours.
- The average pertinent man-hours are then multiplied by the applicable efficiency rate. This produces the average man-hour savings achievable.
- The average man-hour savings achievable figures are then multiplied by the E-5 composite labor rate ($23.19 FY 1994 dollars in this case) to derive average MMH cost savings.

C. F/A-18C *HORNET* AVERAGE MMH COST SAVINGS

Practicality, convenience, time zones and close geographic proximity pointed the authors in the direction of NAS Lemoore to gather research data. The AIMD assistant aircraft maintenance officer was a former NPS graduate and familiar with the topic of expert systems. He offered the quality assurance/analysis division as the best choice, in terms of experience and expertise, to assist the authors with data assimilation.

AIMD quality assurance representatives (QARs) provided the *Hornet's* fault isolation percentages and pertinency rates at the O- and I-levels. It is the author's experience that most QARs at any AIMD have had previous O-level experience. Also, these top performers are often among the most experienced and senior technicians in the organization. QARs familiar with the various O- and I-level components consulted with respective maintenance technicians who fault isolate, replace, and repair the specific components in question.

1. O-Level Cost Savings

At the O-level, technicians determined that expert systems would not be applicable to fault isolate the top five component MMH consumers. Their experience indicated the top five component cause of malfunctions (corrosion, nicked/chipped, cracked/crazed, wear, defective connections) were readily identified using conventional methods. Therefore, no fault isolation percentages or pertinency rates applied at the O-level. As a result, no F/A-18C *Hornet* average MMH cost savings were computed for the O-level.

2. I-Level Cost Savings

At the I-level, the first three component MMH consumers were associated with the weapons control system (WUC 74). These components included the APG65 radar transmitter, APG65 receiver exciter and APG65 antenna. The fourth and fifth leading component MMH consumers were the ASW44 pitch-roll-yaw computer and the ARC radio receiver/transmitter. The technicians estimated they spent 25 percent of their time fault isolating these components.

Pertinency rate estimates varied amongst components. For the APG65 components, technicians assigned a 75 percent pertinency rate, indicating that an average technician or domain expert assistance was required 75 percent of the time in fault isolation. They estimated a 50 percent pertinency rate for the ASW44 pitch-roll-yaw computer and a 30 percent pertinency rate for the ARC radio receiver/transmitter. This is due to the greater effectiveness of current diagnostic methods, repair manuals and less complexity involved with these systems.

Table XI lists the cost saving estimates for the F/A-18C *Hornet* if expert systems were employed at the I-level. The computations yielded an annual MMH cost savings range of $108,396.34 to $139,366.73 using 70 and 90 percent expert system efficiency rates. The three APG65 components account for approximately 84 percent of this savings, or between $91,225.40 and $117,289.80.

D. E-2C *HAWKEYE* AVERAGE MMH COST SAVINGS

Again, practicality, convenience, time zones and geographic proximity pointed the authors in the direction of NAS Miramar as the logical choice for gathering E-2C *Hawkeye* data. QARs from AIMD NAS Miramar provided the *Hawkeye's* maintenance information. These technicians possessed a comprehensive knowledge and experience base of the *Hawkeye's* avionics, power plants, airframes and electrical systems at the O- and I-levels.

In addition to O-level avionics/armament and quality assurance/analysis division experience, the I-level avionics technician has supervised the operation and maintenance of Radar Countermeasures (RADCOM) test benches and module/micro-miniature repair branch at the I-level. He was familiar with each of the top five component MMH consumers and their respective fault isolation/replacement/repair procedures at the I-level.

1. O-Level Cost Savings

The O-level's top five component cause of malfunctions were not considered overly complex to fault isolate. Based on the technicians' input, an expert system was not needed to help fault isolate these five systems/components. Chapter III, Table V may be consulted to refresh the readers' memory of the *Hawkeye's* O-level maintenance data.

The propeller/power plant systems technicians foresaw no expert system applicability for the variable pitch propeller, power plant installation/engine assembly or propeller control assembly. These were the first, second and fifth highest MMH consumers, respectively. They believed the MIMs adequately document the commonly encountered malfunctions and corrective action procedures for the related systems/components.

The electrical systems technician did not feel expert system technology was applicable to the utility light, the third highest MMH consumer. This was due to the simplistic light design and the ease to rapidly correct related malfunctions.

Component	APG65 Radar Transmitter	APG65 Rcvr Exciter	APG65 Antenna	ASW44 Computer	ARC Radio Rcvr/Trans
MMHs	11,493.5	10,579.8	7,898.7	5,570.3	4,819.9
Fault Isolation Percentage	0.25	0.25	0.25	0.25	0.25
Average Fault Isolation Man-Hours	2,873.38	2,644.95	1,974.68	1,392.58	1,204.98
Pertinency Rate	0.75	0.75	0.75	0.50	0.30
Average Pertinent Man-Hours	2,155.03	1,983.71	1,481.01	696.29	361.49
Efficiency Rates	0.70	0.70	0.70	0.70	0.70
	0.90	0.90	0.90	0.90	0.90
Average Man-Hour Savings Achievable					
Efficiency Rate=0.70	1,508.52	1,388.60	1,036.70	487.40	253.04
Efficiency Rate=0.90	1,939.53	1,785.34	1,332.91	626.66	325.34
E-5 Composite Labor Rate	$23.19	$23.19	$23.19	$23.19	$23.19
Average MMH Cost Savings					
Efficiency Rate=0.70	$34,982.62	$32,201.61	$24,041.17	$11,302.83	$5,868.11
Efficiency Rate=0.90	$44,977.66	$41,402.06	$30,910.08	$14,532.22	$7,544.71

Table XI. F/A-18C *Hornet* Average MMH Cost Savings Using Expert Systems at the I-Level (FY 1994)

The airframes system technician also felt that an expert system was not applicable to the rudder system, the fourth highest MMH consumer. This was due to the nature of commonly encountered malfunctions and the adequacy of MIMs to help fault isolate/ replace/repair rudder system components.

2. I-Level Cost Savings

The I-level avionics technician foresaw potential MMH cost savings for the two azimuth range indicators (WUCs 726J2, 726J4) if expert systems were used at the I-level. He indicated that 65 percent of the MMHs were attributable to fault isolation.
These items are fairly time consuming to diagnose. A 35 percent pertinency rate was assigned for the expert system. The MIMs and current diagnostic methods are fairly effective for these components. The combined MMH cost savings for these two components would then yield between $27,190.51 and $34,959.23 annually.

Records indicate very little time was spent fault isolating the AIC14 ICS control (approximately 10 percent). This was due to rapid and effective diagnosis when the RADCOM test bench was used. Thus, expert systems were not needed to facilitate the ICS control maintenance effort. Fault isolation percentages and pertinency rates were not applicable.

The digital data converter and computer are also tested on the RADCOM test benches. Technicians estimated a 40 percent fault isolation rate of overall MMHs and a 50 percent pertinency rate due to the components' complexity. The combined MMH cost savings for these components only yield $66.88 to $85.99 annually because the components failed infrequently.

The azimuth range indicator components are part of the larger main display unit (MDU) systems in the aft crew area of the E-2C. These units are being replaced by the newer enhanced main display unit (EMDU) systems. There was not any available EMDU data at NALDA since these units were still under contract support.

AIMD did not possess the repair capability for the EMDU systems, but there was a tentative test program system anticipated for the RADCOM test benches. This means the units are presently beyond the repair capability of I-level maintenance and are forwarded to the D-level for repair.

At the D-level, Grumman Aerospace Company technical representatives perform the diagnosis and repair of EMDUs using laptop computer technology. The avionics technician anticipated increased EMDU fault isolation percentages and pertinency rates upon entrance into the AIMD repair pipeline. Table XII displays the potential *Hawkeye's* MMH cost savings at the I-level.

E. S-3B *VIKING* AVERAGE MMH COST SAVINGS

NAS North Island was chosen as the site for gathering S-3B data for the same reasons as the F/A-18C and E-2C, its geographic closeness. The authors chose VS-33 as the representative O-level activity. We knew the maintenance/material control officer (MMCO) and the squadron was not deployed. The MMCO recommended that the authors contact Mr. Jim Vizzard (Lockheed technical representative) at AIMD. He has a reputation as the *Vikings'* I-level expert.

1. O-Level Cost Savings

The O-level avionic and electrical system technicians indicated an expert system would be extremely beneficial in fault isolating the ASW33 flight data computer broken wire/defective contact/connection cause of malfunction.

They felt an expert system would be beneficial because the number of MIMs that must be consulted, to trace out computer wire bundle runs, made fault isolation a complex and time consuming process. Using an expert system would reduce the MIM requirements. It was believed that fault isolation time could be significantly reduced.

Also, by using diagrams and pictures in the expert system, the location of plugs and connectors could be readily identified. This would be especially helpful to inexperienced technicians. It would allow them to rapidly locate potential computer related problems without the aid of an experienced technician as is often the case now.

Component	Az Range Indicator	AIC14 ICS Control	Az Range Indicator	Dgtl Data Converter	Dgtl Data Computer
MMHs	7,160.5	2,491.9	202.2	17.0	3.6
Fault Isolation Percentage	0.65	0.10	0.65	0.40	0.40
Average Fault Isolation Man-Hours	4,654.33	249.19	131.43	6.80	1.44
Pertinency Rate	0.35	0.00	0.35	0.50	0.50
Average Pertinent Man-Hours	1,629.01	0.00	46.00	3.40	0.72
Efficiency Rates	0.70	0.70	0.70	0.70	0.70
	0.90	0.90	0.90	0.90	0.90
Average Man-Hour Savings Achievable					
Efficiency Rate=0.70	1,140.31	0.00	32.20	2.38	0.50
Efficiency Rate=0.90	1,466.11	0	41.40	3.06	0.65
E-5 Composite Labor Rate	$23.19	$23.19	$23.19	$23.19	$23.19
Average MMH Cost Savings					
Efficiency Rate=0.70	$26,443.78	$0.00	$746.73	$55.19	$11.69
Efficiency Rate=0.90	$33,999.15	$0.00	$960.08	$70.96	$15.03

Table XII. E-2C *Hawkeye* Average MMH Cost Savings Using Expert Systems at the I-Level (FY 1994)

A third expert system benefit could be the reduction of A-799 WRAs that were unnecessarily removed and replaced in fault isolating ASW33 flight data computer discrepancies. A-799s contributed only three percent to the total ASW33 flight data computer failures (34 A-799s divided by 1155 ASW33 flight data computer failures in FY 1994).

The technicians estimated a fault isolation percentage of 60 percent and a pertinency rate of 80 percent due to system complexity and the effectiveness of technical publications. Based on these estimates, the ASW33 flight data computer MMH yearly cost savings would be between $21,014.59 and $27,018.76.

The switch logic unit and integrated radio controller were related system units. They were both subject to the same broken wire/defective contact/connection cause of malfunction. Fault isolation time could be reduced by the use of an expert system according to the technicians. Their reasoning was similar to the previous fault isolation problem for the ASW33 flight data computer. In addition, it was also pointed out that expert system usage would be beneficial in fault isolating the "no output" cause of malfunction.

This analogy seemed logical because "no output" was a leading cause of failure for the switch logic unit and integrated radio controller. Technicians stated that the "no output" malfunction routinely consumed a large amount of MMHs. Their experience indicated that the fault isolation process was lengthy in trying to narrow the common failure causes to such items as a defective circuit breaker, blown fuse, open ground, bad power supply or combination.

An expert system that stores the indications associated with the causes of component failure and is able to determine the correct remedies to make the systems or components serviceable would be valuable. Both technicians agreed such technology could reduce the number of MMHs.

For example, with a fault isolation percentage and pertinency rate for the *Viking* switch logic unit and integrated radio controller of 80 percent each, the combined MMH cost savings would be between $45,387.99 to $58,355.98. Table XIII lists the *Viking's* potential O-level cost savings.

2. I-Level Cost Savings

The I-level avionics expert was a Lockheed technical representative assigned to AIMD North Island. He spent most of his time fault isolating WRAs/SRAs. He has been involved with S-3B repair for many years. His current specialty is avionics repair using the Versatile Avionics Shop Test (VAST) bench system. VAST is capable of diagnosis and repair of a wide variety of aircraft weapon systems.

VAST benches exist both ashore and afloat and have been in existence for many years. They are physically large and complex, requiring considerable set-up time. They are scheduled to be replaced by the modern Consolidated Automated Support System (CASS) in November 1995.

Out of the "Top 5" *Viking* I-level component MMH consumers, the first four WRAs are diagnosed and repaired using the VAST test bench. The four include the ASW33 flight data computer, the switch logic unit, the navigational data converter and the ARC156 radio receiver/transmitter. All of these components suffer from similar malfunctions: a broken wire/ defective contact/connection, failed diagnostic/automatic tests, and improper adjustment/alignment. These malfunctions produce the majority (over 93 percent) of associated discrepancies for these components.

Since the technical representative spent most of his time fault isolating WRAs/SRAs on the VAST bench, he recommended fault isolation time as 60 percent of the MMHs. His pertinency rate was estimated to be 15 percent. He anticipated more benefits from expert systems once the new CASS replaces the much older VAST bench. The fact that the VAST bench will soon be replaced is a prime reason for not considering development of an expert system for it. There is neither the time necessary for development nor a large enough return on investment.

Calling upon the technical representative's comprehensive experience with the S-3B *Viking*, an inquiry was also made into the applicability of an expert system for diagnosing the fifth leading MMH consumer, wheel/tire assemblies and related

Component		ASW33 Flight		Switch Logic		Integrated Radio
		Data Computer		Unit		Controller
MMHs		2,697.0		2,489.4		1,879.4
Fault Isolation		0.60		0.80		0.80
Percentage						
Average Fault		1,618.20		1,991.52		1,503.52
Isolation Man-Hours						
Pertinency Rate		0.80		0.80		0.80
Average Pertinent		1,294.56		1,593.22		1,202.82
Man-Hours						
Efficiency Rates		0.70		0.70		0.70
		0.90		0.90		0.90
Average Man-Hour						
Savings Achievable						
Efficiency Rate=0.70		906.19		1,115.25		841.97
Efficiency Rate=0.90		1,165.10		1,433.89		1,082.53
E-5 Composite		$23.19		$23.19		$23.19
Labor Rate						
Average MMH						
Cost Savings						
Efficiency Rate=0.70		$21,014.59		$25,862.68		$19,525.31
Efficiency Rate=0.90		$27,018.76		$33,252.01		$25,103.97

Table XIII. S-3B *Viking*MMH Cost Savings Using Expert Systems at the O-Level (FY 1994)

components. He believed these items were solvable using conventional fault isolation methods rather than expert systems. This makes sense. The majority of conventional fault isolation methods used on these components are eddy-current and magnetic particle inspections or the MIMs. They provide an adequate fault isolation capability.

Based upon the information related to the first four top MMH consumers at the I-level, expert systems incorporation could save an estimated $39,218.72 to $50,424.06 in MMH costs annually. While this is not overwhelming savings, it is primarily due to the current VAST limitations (20 year old design, complexity, lengthy set up and run time). Benefits are anticipated to increase with the introduction of CASS. Table XIV illustrates the procedures used for determining MMH cost savings.

After examining the results of the work that produced Tables XI-XIV, the authors' concluded that the method used had weaknesses. The data was extrapolated from NALDA and fault isolation percentages and pertinency rates were based on phone interviews. The question was raised as to whether this was a truly objective and quantitative method or was the method too subjective and qualitative. It sorted out to be a combination of both methods.

Much was learned in the gathering of data and interviews. In critically examining the initial effort, the researchers were able to formulate a basic empirical model for estimating potential MMH cost savings by using expert systems to assist in the fault isolation process. A S-3B *Viking* I-level domain expert assisted in the development of the model and furnished data used in the following example.

F. THE SHIRKEY-SCHANZ EXPERT SYSTEM MAINTENANCE MAN-HOUR COST SAVINGS MODEL

In the course of this research, it became evident that the S-3B *Viking's* I-level process presented an opportunity for developing an empirical model that could be used to assess potential MMH cost savings when an expert system is incorporated into the diagnostic process. Each of the top four I-level MMH consumers for the S-3B is repaired

Component	ASW33 Flight Data Computer	Switch Logic Unit	Navigation Data Converter	ARC156 Radio Rcvr/Trans
MMHs	8,498.2	6,565.6	6,292.7	5,487.8
Fault Isolation Percentage	0.60	0.60	0.60	0.60
Average Fault Isolation Man-Hours	5,098.92	3,939.36	3,775.62	3,292.68
Pertinency Rate	0.15	0.15	0.15	0.15
Average Pertinent Man-Hours	764.84	590.90	566.34	493.90
Efficiency Rates	0.70	0.70	0.70	0.70
	0.90	0.90	0.90	0.90
Average Man-Hour Savings Achievable				
Efficiency Rate=0.70	535.39	413.63	396.44	345.73
Efficiency Rate=0.90	688.35	531.81	509.71	444.51
E-5 Composite Labor Rate	$23.19	$23.19	$23.19	$23.19
Average MMH Cost Savings				
Efficiency Rate=0.70	$12,415.62	$9,592.14	$9,193.45	$8,017.51
Efficiency Rate=0.90	$15,962.93	$12,332.76	$11,820.14	$10,308.23

Table XIV. S-3B *Viking* Average MMH Cost Savings Using Expert Systems at the I-Level (FY 1994)

on the VAST bench by maintenance technicians. In a significant number of cases, a domain expert is required to assist in determining the fault. In this case, the domain expert (a Lockheed technical representative from NAS North Island) explained that he would group faulty components into four categories, based upon the amount of time consumed in fault isolation. The four categories have been designated as average, difficult, complex and unrepairable.

An **average component** is one which current procedures (i.e., publications, test programs, and average technician aptitude) result in the successful isolation and repair of the malfunction. For model purposes, the authors designated the MMH associated with an average component as ***factor A***.

A ***difficult component*** is a component requiring factor A MMHs, plus the additional fault isolation time of a human expert (highly experienced Naval technician or NETS/CETS technical representative) to successfully repair the component. A difficult component's MMHs are designated as ***factor B***.

A **complex component** refers to a component which is eventually successfully repaired at the I-level, requiring both factors A and B, plus additional fault isolation time by a domain expert. A complex component's MMHs are designated as ***factor C***.

An ***unrepairable component*** refers to a component that is considered unrepairable at the I-level. It is comprised of the time associated with factors A, B, and C, plus additional time up to a maximum preset number of fault isolation hours. These components are considered beyond the organization's repair capability and are forwarded to the next higher repair facility. They are termed "BCM", beyond the capability of maintenance. MMHs associated with an unrepairable component is designated as ***factor D***.

The Expert System MMH Cost Savings Model that follows consists of an eight step process. The discussion below defines each step in the model. S-3B data is then used to demonstrate the application of each step.

Step 1

Assign fault isolation times to each component category (factors A, B, C, and D). The time assignments are determined by grouping components in the four categories and analyzing the fault isolation times for each category. While the example that follows uses set times, the reader should understand that these times may vary for other aircraft systems based upon real world experience and practices.

For the S-3B top four MMH consumers, average components (factor A) make up 60 percent of all components. Average components are fault isolated, on average, in one hour. Malfunctions of this type consist primarily of components which involve straight-forward diagnosis and replacement of a single SRA.

Difficult components (factor B) make up 30 percent of all components. The average fault isolation time for this category was three hours. Thus, total fault isolation time averages four hours (1 hour (A) + 3 hours (B)) for components in this category. These components often entail some ambiguities in the fault isolation process, sometimes being isolated to more than one SRA. They usually involve basic SRA replacement.

Complex components (factor C) make up approximately five percent of all components. The fault isolation time for this category was two additional hours. Total fault isolation time averages six hours (1 hour (A) + 3 hours (B) + 2 hours (C)) for components in this category. For example, these discrepancies may entail difficult to diagnose chassis wiring problems. But they are still repairable if adequate expertise is available.

Unrepairable components (factor D) make up five percent of the components. The fault isolation time policy for these components allows for an additional two hours before the components are determined to be unrepairable. Total fault isolation time for unrepairable components averaged eight hours (1 hour (A) + 3 hours (B) + 2 hours (C) + 2 hours (D)). These components may involve chassis wiring problems. Fault isolation is complex and time consuming, often requiring more than eight hours to accomplish. After eight hours, the technical representative deems the component beyond economical repair at the I-level and the component is forwarded to the D-level.

Step 2

Assign a MMH cost per hour for each of the fault isolation factors defined in step 1.

For our model, the MMH cost per hour is referred to as ***factor M***. The MMH cost per hour for the various military paygrades can be determined by consulting the NAVCOMPT Notice 7041. Also, Table I located in Chapter II of this study, depicts the MMH cost per hour calculation process.

The MMH cost per hour is $23.19 (FY 1994) based on an E-5 paygrade for this example model.

Step 3

Determine the total number of component failures over a given time frame.

The total number of component failures is designated as ***factor N***. The total number of failures can be extracted from the NALDA data base. The time frame used to determine N is assigned by the person conducting the study.

The example model uses 1,000 failed components over a one year period.

Step 4

Allocate the percentage of the total number of component failures to each of the four categories.

A domain expert would determine these percentages based on personal experience with the test facilities, technicians, and components. The domain expert would also consider local policy as to when components are considered beyond economic repair of the maintenance organization.

For this model the following variables are assigned. $\mathbf{P_1}$ is the percentage of failed components associated with factor A. $\boldsymbol{P_2}$ is the percentage of failed components associated with factor B. $\boldsymbol{P_3}$ is the percentage of failed components associated with factor C. $\boldsymbol{P_4}$ is the percentage of failed components associated with factor D.

As discussed under step 1, the domain expert assigned a category breakout of the following in our example: P_1 is 60 percent (i.e., 60 percent of all the components were categorized as average, having a fault isolation time of one hour), P_2 is 30 percent, P_3 is 5 percent, and P_4 is 5 percent.

Step 5

Determine the Total MMH Cost.

This is a two step process. First each set of category variables (A, M, N, P_1), (B, M, N, P_2), (C, M, N, P_3), (D, M, N, P_4) is multiplied by its respective variables. This will provide a MMH cost per category. Secondly, the four categories are summed together. This produces the Total MMH Cost. The Total MMH Cost is represented by the following.

$$
\begin{aligned}
\textbf{Total MMH Cost} &= (A \times M \times N \times P_1) \\
&+ (B \times M \times N \times P_2) \\
&+ (C \times M \times N \times P_3) \\
&+ (D \times M \times N \times P_4)
\end{aligned}
$$

If we use the example data used in the discussion, the following applies:

Factor A=1 Hr	Factor M=$23.19	Factor N=1,000	P_1 = 60%
Factor B=4 Hrs			P_2 = 30%
Factor C=6 Hrs			P_3 = 5%
Factor D=8 Hrs			P_4 = 5%

$$
\begin{aligned}
\text{Total MMH Cost} &= (1 \times \$23.19 \times 1{,}000 \times 60\%) \\
&+ (4 \times \$23.19 \times 1{,}000 \times 30\%) \\
&+ (6 \times \$23.19 \times 1{,}000 \times 5\%) \\
&+ (8 \times \$23.19 \times 1{,}000 \times 5\%) \\
&= \$57{,}975.00
\end{aligned}
$$

This amount is the total MMH cost at the I-level for all of the top four components.

Step 6

Determine the impact of applying an expert system to assist in the fault isolation process.

This figure will be a percentage of the overall fault isolation time for each category (factors A, B, C, D). The reduced factors are designated as: ***factor A_1, factor B_1, factor C_1***, and possibly ***factor D_1.***

The domain expert believed that for average components, factor A was already at a minimum in terms of fault isolation efficiency. It would benefit little from expert system technology. However, when applying an expert system to the fault isolation process, we would expect that each category of component may expect some improvement (i.e.,reduction) in the fault isolation time. This is because, even for average components, when examining the process domain experts will likely add some heuristics to the fault isolation process, thus improving it. Difficult and complex components (factors B and C) are the categories that would benefit the most from expert system technology for the S-3B components used in this example. Previous experience of the thesis advisor suggests that factor B's and factor C's fault isolation times could be expected to be reduced, in the range of 30 to 90 percent by applying the knowledge of an expert system.

First, using a conservative approach based on the assumption that expert system technology would reduce the fault isolation time of factor B and factor C each by 30 percent, factors B_1 and C_1 are calculated as follows:

Factor A	= 1 Hr = Factor A_1
Factor B	= Factor A + 3 Hrs = 4 Hrs
Factor B_1	= 1 Hr + 3 Hrs(100%-30%) = 1 Hr + 2.1 Hrs = <u>3.1Hrs</u>
Factor C	= Factor A + Factor B + 2 Hrs = 6 Hrs
Factor C_1	= 1 Hr + 3 Hrs(100%-30%) + 2 Hrs(100%-30%) = 1 Hr + 2.1 Hr + 1.4 Hrs = <u>4.5 Hrs</u>

One should note that the application of an expert system to difficult or complex fault isolation tasks results in an overall 22.5 percent and 25 percent reduction in factors B and C respectively.

Using a somewhat more aggressive, but still reasonable approach of a 70 percent reduction through the use of an expert system, the following figures result:

Factor A	$= 1$ Hr $=$ Factor A_1
Factor B	$=$ Factor A $+ 3$ Hrs $= 4$ Hrs
Factor B_1	$= 1$ Hr $+ 3$ Hrs(100%-70%)
	$= 1$ Hr $+ 0.9$ Hrs $=$ <u>1.9Hrs</u>
Factor C	$=$ Factor A $+$ Factor B $+ 2$ Hrs $= 6$ Hrs
Factor C_1	$= 1$ Hr $+ 3$ Hrs(100%-70%) $+ 2$ Hrs(100%-70%)
	$= 1$ Hr $+ 0.9$ Hrs $+ 0.6$ Hrs $=$ <u>2.5 Hrs</u>

Again, the use of an expert system shows considerable potential reduction in fault isolation. At a 70 percent value, overall fault isolation times decline by 52.5 percent and 58.3 percent for difficult and complex components.

Step 7

Calculate the Revised Total MMH Cost.

The Revised Total MMH Cost is calculated using steps 1 through 5. One must ensure the new A_1, B_1, C_1, and D_1 factors are used. When applicable, the recalculated cost model then becomes:

$$\textit{Revised MMH Cost} = (A \times M \times N \times P_1) + (B_1 \times M \times N \times P_2) + (C_1 \times M \times N \times P_3) + (D \times M \times N \times P_4)$$

Using the 30 percent improvement in fault isolation gained using an expert system, the revised MMH cost would be as follows:

Example data:

Factor A	= 1 Hr	Factor M = \$23.19	Factor N = 1,000	P_1 = 60%
Factor B_1	= 3.1 Hrs			P_2 = 30%
Factor C_1	= 4.5 Hrs			P_3 = 5%
Factor D	= 8 Hrs			P_4 = 5%

$$
\begin{aligned}
\text{Revised MMH Cost} &= (1.0 \times \$23.19 \times 1{,}000 \times 60\%) \\
&+ (3.1 \times \$23.19 \times 1{,}000 \times 30\%) \\
&+ (4.5 \times \$23.19 \times 1{,}000 \times 5\%) \\
&+ (8.0 \times \$23.19 \times 1{,}000 \times 5\%) \\
&= \$49{,}974.45
\end{aligned}
$$

The MMH cost savings from using an expert system estimated to provide a 30 percent would be 13.8 percent. Recall this savings is figured using only the top four MMH component consumers. Using the higher 70 percent factor, the result would be:

Factor A	= 1 Hr	Factor M = \$23.19	Factor N = 1,000	P_1 = 60%
Factor B_1	= 1.9 Hrs			P_2 = 30%
Factor C_1	= 2.5 Hrs			P_3 = 5%
Factor D	= 8 Hrs			P_4 = 5%

$$
\begin{aligned}
\text{Revised MMH Cost} &= (1.0 \times \$23.19 \times 1{,}000 \times 60\%) \\
&+ (1.9 \times \$23.19 \times 1{,}000 \times 30\%) \\
&+ (2.5 \times \$23.19 \times 1{,}000 \times 5\%) \\
&+ (8.0 \times \$23.19 \times 1{,}000 \times 5\%) \\
&= \$39{,}307.05
\end{aligned}
$$

The MMH cost savings from using an expert system estimated to provide a 70 percent would be 32.2 percent. Recall this savings is figured using only the top four MMH component consumers.

Step 8

Determine the Expert System MMH Cost Savings.

The Expert System Cost Savings is determined by subtracting the Revised MMH Cost from the Total MMH Cost, i.e., ***Expert System MMH Cost Savings*** =Total MMH Cost - Revised MMH Cost.

The S-3B I-level model expert system MMH cost savings is derived as follows: Using a 30 percent MMH reduction:

		\$57,975.00
	-	\$49,974.45
Expert system MMH cost savings =		\$ 8,000.55 savings

Using a 70 percent MMH reduction:

		\$57,975.00
	-	\$39,307.05
Expert system MMH cost savings =		\$18,667.95 savings

Table XV summarizes the MMH and MMH cost savings from using an expert system to fault isolate I-level discrepancies on the S-3B.

Factors D and D_1 are assumed to be constant and beyond the range of expert system improvement since these components are beyond the economical repair capability of the domain expert.

	Original MMHs	MMHs Saved	MMH Cost Per Hour	Cost Savings	% of MMHs Saved
Expert System Impact of 30%	2,500 MMHs	345 MMHs	$23.19	$8,000.55	13.8%
Expert System Impact of 70%	2,500 MMHs	805 MMHs	$23.19	$18,667.95	32.2%

Table XV. Expert System Impact on S-3B MMHs and MMH Cost Savings

Another way is to look at the savings on a per component basis. The example model consists of 1,000 components. The average cost savings per component is as follows:

The average MMH cost per component was $57.98.

Using a 30 percent MMH reduction:

$8,000.55/1,000 components = $8.00/component.

This represents a 13.8 percent savings per component.

Using a 70 percent MMH reduction:

$18,667.95/1,000 components = $18.67/component

This represents a 32.2 percent savings per component.

The examples used in the model are presented, in condensed versions, for both a 30 and 70 percent MMH reduction in Figures 1 and 2 at the end of this chapter.

G. SUMMARY

This chapter documented the potential applicability of expert systems to shorten the fault isolation time for specific aircraft components. It documents the initial approach taken. It was presented to serve as a demonstration of the kind of path future researchers may initially wish to consider, but as was learned in this research, they should not. The second portion of the chapter presented an empirical model that was developed to estimate the MMH cost savings from using expert systems technology. Chapter VI delineates research questions and answers, conclusions, lessons learned, and recommendations for further research.

Total MMH Cost $= (A \times M \times N \times P_1) + (B \times M \times N \times P_2) + (C \times M \times N \times P_3) + (D \times M \times N \times P_4)$

Step 1		Step 2	Step 3	Step 4
Factor A	= 1.0 Hour	M = $23.19	N = 1,000	$P_1 = 60\%$
Factor B	= 4.0 Hours			$P_2 = 30\%$
Factor C	= 6.0 Hours			$P_3 = 5\%$
Factor D	= 8.0 Hours			$P_4 = 5\%$

Step 5

Total MMH Cost = (1.0 x $23.19 x 1,000 x 60%)
+ (4.0 x $23.19 x 1,000 x 30%)
+ (6.0 x $23.19 x 1,000 x 5%)
+ (8.0 x $23.19 x 1,000 x 5%)
= **$57,975.00**

Step 6

If B = Factor A + 3 Hrs, then

B_1 = 1 Hr + 3 Hrs(100%-30%)
= 1 Hr + 2.1 Hrs
= 3.1 Hrs

If C = Factor A + Factor B + 2 Hrs, then

C_1 = 1 Hr + 3 Hrs(100%-30%) + 2 Hrs(100%-30%)
= 1 Hr + 2.1 Hrs + 1.4 Hrs
= 4.5 Hrs

Step 7

Revised MMH Cost $= (A \times M \times N \times P_1) + (B_1 \times M \times N \times P_2) + (C_1 \times M \times N \times P_3) + (D \times M \times N \times P_4)$

Revised MMH Cost = (1.0 x $23.19 x 1,000 x 60%)
+ (3.1 x $23.19 x 1,000 x 30%)
+ (4.5 x $23.19 x 1,000 x 5%)
+ (8.0 x $23.19 x 1,000 x 5%)
= **$49,974.45**

Step 8

Expert System MMH Cost Savings = Total MMH Cost - Revised MMH Cost
= $57,975.00 - $49,974.45
= **$8,000.55**

Figure 1. 30 Percent MMH Reduction (Example Model)

Total MMH Cost $= (A \times M \times N \times P_1) + (B \times M \times N \times P_2) + (C \times M \times N \times P_3) + (D \times M \times N \times P_4)$

Step 1

Factor A = 1.0 Hour
Factor B = 4.0 Hours
Factor C = 6.0 Hours
Factor D = 8.0 Hours

Step 2

$M = \$23.19$

Step 3

$N = 1{,}000$

Step 4

$P_1 = 60\%$
$P_2 = 30\%$
$P_3 = 5\%$
$P_4 = 5\%$

Step 5

Total MMH Cost $= (1.0 \times \$23.19 \times 1{,}000 \times 60\%) + (4.0 \times \$23.19 \times 1{,}000 \times 30\%) + (6.0 \times \$23.19 \times 1{,}000 \times 5\%) + (8.0 \times \$23.19 \times 1{,}000 \times 5\%)$
= \$57,975.00

Step 6

If B = Factor A + 3 Hrs, then
B_1 = 1 Hr + 3 Hrs(100%-70%)
= 1 Hr +0.9 Hrs
= 1.9 Hrs

If C = Factor A + Factor B + 2 Hrs, then
C_1 = 1 Hr + 3 Hrs(100%-70%) + 2 Hrs(100%-70%)
= 1 Hr + 0.9Hrs + 0.6 Hrs
= 2.5 Hrs

Step 7

Revised MMH Cost $= (A \times M \times N \times P_1) + (B_1 \times M \times N \times P_2) + (C_1 \times M \times N \times P_3) + (D \times M \times N \times P_4)$

Revised MMH Cost $= (1.0 \times \$23.19 \times 1{,}000 \times 60\%) + (1.9 \times \$23.19 \times 1{,}000 \times 30\%) + (2.5 \times \$23.19 \times 1{,}000 \times 5\%) + (8.0 \times \$23.19 \times 1{,}000 \times 5\%)$
= \$39,307.05

Step 8

Expert System MMH Cost Savings = Total MMH Cost - Revised MMH Cost
= \$57,975.00 - \$39,307.05
= **\$18,667.95**

Figure 2. 70 Percent MMH Reduction (Example Model)

VI. RESEARCH QUESTIONS AND ANSWERS/CONCLUSIONS/ LESSONS LEARNED/RECOMMENDATIONS

Naval aviation maintenance managers are responsible for ensuring aircraft maintenance continues to be performed in a safe, efficient manner. This proves to be a continual challenge considering declining DOD resources, the decommissioning of aircraft squadrons and a general reduction in forces.

Maintenance managers must continually seek new ways to optimize scarce resources and assist technicians with maintaining aircraft systems/components at all three maintenance levels. Currently, aviation maintenance technicians and technical representatives use conventional fault isolation methods to return aircraft systems/components to a functional status.

These conventional fault isolation methods consume an enormous amount of MMHs. Since both authors are experienced aviation maintenance managers, the decision was made to investigate a potential resource to possibly reduce the consumption of MMHs. This is why the authors chose to introduce the concept of applying expert systems to help diagnosis aircraft discrepancies. The primary objective of this research was to determine a process for determining the impact on direct labor MMHs of applying expert systems to assist in diagnosis of aircraft discrepancies. The secondary objective of this research was to identify direct labor MMH costs associated with *Hornet*, *Hawkeye*, and *Viking* aircraft at the organizational and intermediate maintenance levels.

The primary research question addressed was:

- What is the empirical model for deriving the potential direct labor MMH cost savings by using expert systems to assist fault isolation of *Hornet*, *Hawkeye* and *Viking* systems/components?

The secondary research questions addressed were:

- What are some of the potential benefits of using expert systems in the Naval aviation maintenance field?

- What are the top five component MMH consumers at the organizational maintenance level for the *Hornet*, *Hawkeye* and *Viking* aircraft during FY 1994?

- What are the top five component MMH consumers at the intermediate maintenance level for the *Hornet*, *Hawkeye* and *Viking* aircraft during FY 1994?

- What are the direct labor MMH costs, using conventional fault isolation methods to identify failed components, for the three aircraft during FY 1994?

A. RESEARCH QUESTIONS AND ANSWERS

This section provides the answers to the primary and secondary research questions.

Can a model be developed to derive the potential direct labor MMH cost savings by using expert systems to assist fault isolation of *Hornet*, *Hawkeye* and *Viking* systems/components?

It was found that it was possible to develop such a model. The Shirkey-Schanz Expert System Maintenance Man-Hour Cost Savings Model was developed by the authors to determine the potential direct labor MMH cost savings from using expert systems to fault isolate aircraft systems/components. The empirical model groups components into categories based upon their average fault isolation times. The component categories were designated average, difficult, complex, or unrepairable. Each category was assigned an average fault isolation time to repair that category of component based upon a domain expert's recommendation. In the example used for this research, if a component required over eight hours of repair it was considered beyond the economical repair capability of the maintenance organization. Such components were classified in the unrepairable category.

The difficult and complex component categories were chosen as targets for potential expert system development. These two categories were primarily chosen because:

1. These components require significantly greater fault isolation times;

2. A key reason for this is that there is a lack of factual/documented knowledge available to the technician;

3. The heuristic knowledge of a technical representative is usually required to correctly fault isolate these components within a reasonable period of time.

The empirical model developed may be used to calculate MMH cost savings at the organizational and intermediate maintenance levels for various type/model/series of aircraft.

What are some of the potential benefits of using expert systems in the Naval aviation maintenance field?

Expert systems offer several potential benefits to the Naval aviation maintenance process. First, is a reduction in MMH because of more efficient and effective fault isolation. Technicians and technical representatives in each of the three aircraft investigated expressed a need for better fault isolation methodologies and techniques for various discrepancy areas. Also, aviation technicians today are never without a sizeable backlog of awaiting maintenance discrepancies. The fact that they are able to reduce their fault isolation time will allow them to use this time to work on this backlog.

A second benefit is improved operational readiness. The fact that an item can be fault isolated more quickly means that the system will be returned to an operationally ready status sooner. Other studies have documented such opportunities, for example, (Powell, 1994).

Many discrepancies require the assistance of a domain expert. Unfortunately, experts can only be at one place at a time; they also have a limited number of hours per day they are available. This brings up a third benefit. Expert systems and the knowledge they contain can be inexpensively reproduced and distributed widely. They can be employed simultaneously at 10 squadrons scattered around the world. An expert system is also available 24 hours a day to provide assistance. Something even the most dedicated expert cannot accomplish 365 days a year.

Expert systems can also improve aircraft maintenance by reducing A-799 rates, i.e., components returned to an RFI status because no defect could be found.

What are the top five component MMH consumers at the organizational maintenance level for the *Hornet*, *Hawkeye* and *Viking* aircraft during FY 1994?

The top five MMH consumers at the O-level for the three aircraft during FY 1994 were:

F/A-18C *Hornet*

Component	MMH
SUU63/A aircraft pylon	3,082.6
LAU7/A guided missile launcher	2,445.9
BRU32/A aircraft ejector bomb rack	1,761.6
Aileron installation	587.0
Main landing gear mechanical installation	251.4

E-2C *Hawkeye*

Component	MMH
Variable pitch propeller	4,808.3
Power plant system install/engine assembly	2,716.0
Utility light	1,639.1
Rudder	1,298.7
Propeller control assembly	510.7

S-3B *Viking*

Component	MMH
ASW33 flight data computer	2,697.0
Switch logic unit	2,489.4
Integrated radio controller	1,879.4
BRU14 bomb rack assembly	877.2
Engine wing pylon installation/assembly	425.8

What are the top five component MMH consumers at the intermediate maintenance level for the *Hornet*, *Hawkeye* and *Viking* aircraft during FY 1994?

The top five MMH consumers at the I-level for the three aircraft during FY 1994 were:

F/A-18C *Hornet*

Component	MMH
APG65 radar transmitter	11,493.5
APG65 receiver exciter	10,579.8
APG65 antenna	7,898.7
ASW44 pitch-roll-yaw computer	5,570.3
ARC radio receiver/transmitter	4,819.9

E-2C *Hawkeye*

Component	MMH
APA172 azimuth range indicator	7,160.5
AIC14 ICS control	2,491.9
APA172 azimuth range indicator	202.2
ASQ digital data converter	17.0
ASQ digital data computer	3.6

S-3B *Viking*

Component	MMH
ASW33 flight data computer	8,498.2
Switch logic unit	6,565.6
ASA84 navigation data converter	6,292.7
ARC156 radio receiver/transmitter	5,487.8
Wheel/tire assembly	191.2

What are the direct labor MMH costs, using conventional fault isolation methods to identify failed components, for the three aircraft during FY 1994?

For *Hornet* maintenance at the organizational and intermediate levels, the total cost was $1,124,499.33 for the top five component MMH consumers. The primary cost drivers occurred at the I-level, which included the weapons control system components (APG65 radar transmitter, APG65 receiver exciter, APG65 antenna). These three components accounted for approximately 62 percent of the total MMH cost. When the authors factored in the ASW44 pitch-roll-yaw computer and radio receiver/transmitter, the I-level accounted for 83 percent of the total direct MMH labor cost.

The *Hawkeye's* total direct labor MMH cost was $483,465.12 for the top five consumers at the O- and I-levels. Organizational level MMH costs accounted for approximately 53 percent of the total cost. The variable pitch propeller was the major O-level cost driver. It accounted for 23 percent of the total direct labor MMH cost.

Forty-seven percent of the *Hawkeye's* total direct labor MMH cost was accumulated at the I-level. The azimuth range indicator (WUC 726J2) was the number one cost driver. It accounted for 34 percent of the total cost.

The total direct labor MMH cost was $821,025.72 for the *Viking's* top five MMH consumers at the O- and I-levels. The organizational maintenance level accounted for 24 percent of the total cost. The ASW33 flight data computer was the number one O-level cost driver at $462,543.43.

The intermediate maintenance level accounted for 74 percent of the total cost. The ASW33 flight data computer again accounted for $197,073.26 or 24 percent of the total cost. The switch logic unit was the second leading cost driver at a cost of $152,256.26 for FY 1994. This was followed by the navigation data converter at a cost of $145,927.71.

B. CONCLUSIONS

From the research completed, the authors have determined it is possible to develop an empirical model to derive potential direct labor MMH cost savings from expert systems. The model is flexible and easily modified to determine MMH cost savings for various type/model/series of aircraft and repair facilities.

The potential benefits of expert systems include reduced MMHs through more efficient and effective fault isolation. Reduced fault isolation also serves to reduce the backlog of awaiting maintenance discrepancies. Another benefit is improved operational readiness by returning systems to ready status sooner through reduced fault isolation time.

The primary MMH consumers for all three aircraft investigated were based on the top five component direct labor MMH consumers. For the *Hornet* the primary cost driver consisted of the APG65 weapons control system, accounting for 62 percent of the total MMH cost at the O- and I- levels. The *Hawkeye's* primary MMH consumer at the O-level was the variable pitch propeller, accounting for 53 percent of the total cost. The azimuth range indicator was the primary cost driver for the *Hawkeye* at the I-level, accounting for 34 percent of the direct labor consumed. The ASW33 was the *Viking's* primary cost driver at the O- and I- levels, accounting for over 80 percent of the total O- and I- level maintenance costs for the top five components.

C. LESSONS LEARNED

This research uncovered several areas that may prove advantageous for further investigation. The authors originally started in the general direction of identifying the cost drivers for several aircraft. The potential application areas for using expert systems was to be made. Determining which area would provide the most meaningful data and specific information, while weeding out areas beyond the scope and time constraints of the thesis, proved to be a major learning experience.

The following areas may provide assistance for those pursuing further investigation into the application of expert systems in the field of Naval aviation maintenance.

1. NALDA

Currently, on line access to the NALDA data base is not available at the Naval Postgraduate School (NPS). Such access would be very valuable in reducing the turn around time required to obtain aircraft maintenance data. The scope of this thesis had to be significantly reduced because the turn around time associated with data gathering was extensive. The data gathering process involved determining a reliable and valid source of data, the methods required to extract the data from an extremely large database, and then processing the data into manageable and meaningful information. Not having direct access to the NALDA database, the authors were fortunate to find an exceptionally astute and cooperative contact at AIMD NAS Lemoore. Our point of contact, AZ1(AW) Gilman, possessed the expertise to extract NALDA data, using the NAS Lemoore access node. We provided the background and purpose of the study and the type of data we were interested in.

Retrieving NALDA data consisted of submitting a request using a password and the required NALDA system data access codes. Turn around time took several work days and resulted in large amounts of raw data. AZ1(AW) Gilman would then process the data into meaningful information necessary to facilitate the thesis effort.

Normal turn around was one or two weeks depending on the amount of data extracted. The information obtained would then be used to determine the fault isolation percentages and pertinency rates from field technicians. The typical time to obtain relevant information from technicians added an additional two to three weeks. Thankfully, AZ1(AW) Gilman unselfishly provided his support.

All in all, gathering data from the NALDA database using the process described was time consuming and not a very efficient process. A significant reduction in communications and the time required to get data from the NALDA database would result if NPS had an on-site access node.

2. Logistics Management Decision Support System (LMDSS)

LCDR Mike Kelly of NAMO provided a demonstration of LMDSS capabilities at NPS in March 1995. Using LMDSS he accessed the NALDA database from NPS terminals and extracted our required data in only 20 minutes. It had taken us months and a trip to NAS Lemoore to obtain similar data. This thesis project is not the only one that has required access to NALDA data. Several other students have completed theses which were dependent on NALDA data. They also faced similar delays in obtaining information because of the difficulty in accessing NALDA.

LMDSS access from NPS would: (1) alleviate data retrieval time delays, (2) reduce thesis travel time, (3) reduce thesis travel costs, and (4) reduce the amount of assistance solicited from fleet personnel.

LMDSS has only been in existence for two years and is accessible via the Internet. The advantages of LMDSS is that it is instinctive, has push button features and is user friendly. It allows the user to access data in a manner similar to a "Windows" graphical user interface application. Data can be gathered based on aircraft type/model/series. The results are tabulated into an easily useable form.

LMDSS access requires authorization by NAMO and hands on training. NPS would have to request such authorization via message or naval letter. For long term continuity, it is recommended that a computer specialist from NPS attend the three- week NAMO LMDSS computer course. If available, a significant number of aerospace maintenance and supply officers would use this resource in their research or course work.

3. Electro-Optical Test Set (EOTS)

NAS Lemoore is considered to have the most successful EOTS repair facility in the Navy. Over the years, the technical representatives have assimilated a tremendous amount of heuristic knowledge that is vital in efficiently repairing the *Hornet's* FLIR system using the test bench. Based on our trip to NAS Lemoore, we believe the EOTS bench at the AIMD would be a prime candidate for the development of an expert system. This knowledge has never been incorporated into the operating procedures and documentation for the system. If the knowledge was encapsulated into an expert system, the impact would prove exceptionally beneficial to Navy maintenance technicians in the field.

Another justification for an expert system is that with decreased funding, it is inevitable that there will be some decrease in the number of NAESU technical representatives in the years ahead. When such experts leave the Navy, the expertise and knowledge they have accumulated over decades will leave with them. An expert system would capture this valuable knowledge.

4. VAST/CASS

With the VAST bench being replaced in late 1995, there is little reason to develop an expert system if development time and potential return on investment are taken under consideration. With CASS introduction into the fleet at the end of calendar year 1995, expert systems technology could find a more applicable avenue for development. CASS will consist of much newer technology requiring development of a new set of heuristic data and test programs. This integrated approach between expert systems and CASS is also the preferred method of incorporation according to a NAVAIRSYSCOM representative. While it is not evident that an expert system in this area would payoff, it seems that this would be a primary area for further study and investigation.

5. A-799

Another area for potential further review would be in the area of A-799s. As mentioned in Chapter II, the term A-799 refers to a specific action taken code. In this case, an item sent to the next higher level of maintenance. Such items are returned to an RFI status because the repair facility could not find an associated component defect. In other words, they are perfectly functional parts.

Because of time and funding constraints we were unable to address this issue in our research. However, we were able to make an initial investigation into A-799s based on an entire system's two-digit WUC. A two digit code is a much more encompassing category, as compared to a five digit WUC for singular components. An entire system is composed of many components which require repair at different types of maintenance facilities. For example, a two digit WUC would fall under the category bombing navigation systems or interphone systems. A five digit WUC includes specific components of the system, such as a navigational data converter or a switch logic unit.

Potential A-799 areas to investigate include the full cost and the net price of a system component. By investigating these two areas, the current procurement cost, current repair cost, depot washout factor and carcass loss factor of a component can be determined. Also, a component surcharge is applied to both the full cost and net price of a component. Therefore, the authors recommend investigating the component surcharge issue since the following costs may be revealed: (1) supply operations, (2) transportation, (3) inventory losses, (4) obsolescence, (5) inflation, and (6) inventory management.

MMHs expended by military, civilian and contractor personnel and other cost considerations, such as direct labor MMH costs, indirect costs (e.g., travel costs) and overhead costs, lend themselves to investigation. Lastly, the impact of A-799s on operational readiness can be investigated.

Appendix B is a suggested flow chart representation of the A-799 issues discussed. An in-depth examination of A-799 issues, on a single aircraft system, could easily encompass an entire single thesis topic. We believe such a study is warranted.

6. NETS/CETS

NETS/CETS man-hours were explored as a potential area in which to reduce costs by applying expert systems. Unfortunately, the differences between military man-hour accounting methods compared with civilian man-hour accounting methods could not be resolved. Military man-hours are accounted for on the VIDS/MAFs, and were accessible via the NALDA database. The civilian man-hours were broken down into more general tasking areas.

Due to insufficient time, we were not able to further explore the NETS/CETS man-hour issues to obtain potential cost saving estimates. This topic could be another potential thesis for students who endeavor to "crack the code" of compatibility between military and civilian man-hour accounting systems.

D. RECOMMENDATIONS

Based upon research conducted in this thesis, conclusions and lessons learned in the previous section, the following recommendations are offered:

- Recommend future research be conducted to determine the applicability of expert systems to help fault isolate *Hornet* I-level components. Expert systems appear to be applicable to help maintenance technicians fault isolate the *Hornet's* APG65 radar transmitter, APG65 receiver exciter, and APG65 antenna at the I-level. Based on conversations with technicians, the three APG65 components are categorized as difficult or complex components. This marks the three components as prime candidates to apply expert systems to reduce the fault isolation times, reduce MMHs and save money.

- Continue pursuit of LMDSS access from NPS. This could greatly enhance the research capabilities of faculty and students. Current requirements for data retrieval, thesis travel, travel costs, and assistance from fleet personnel could be reduced if LMDSS access is available from NPS.

- A prime candidate for the development of an expert system is the EOTS facility at AIMD NAS Lemoore. The technical representatives have assimilated a tremendous amount of heuristic knowledge and data that proves vital for the successful repair of fleet assets. The heuristic data enables NAS Lemoore's EOTS facility to maintain itself as the most successful repair facility of its type in the fleet. Development of an expert system could preserve the vital repair data and prevent its loss in the event that some technical representatives support is further reduced.

- The authors recommend further investigation into the implementation of expert systems into the upcoming CASS since the current VAST system is due for replacement late in calendar year 1995. Expert system heuristics must be kept current and updated for eventual incorporation into test programs as part of a continual improvement process. Continued research into the most promising areas of costs/benefits, compatibility and effectiveness could provide a vital core toward the merging of CASS and its test programs with expert systems.

- The A-799 issue and the application of expert systems in Naval aviation maintenance field is another area that requires investigation. The adverse impact on operational readiness, associated costs, unnecessary removal/replacement of perfectly functional parts and wasted MMHs are only a few good reasons that this area requires investigation.

APPENDIX A. F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 10 SYSTEM FAILURES

FAILURES	BY WUC	ML	
12,469	13		LANDING GEAR
9,986	74		WEAPONS CONTROL SYSTEMS
8,713	14		FLIGHT CONTROLS
7,329	75		WEAPON DELIVERY
4,826	27		TURBOFAN ENGINES
2,690	41		AIR CON/PRSRZ/ICE CONTROL
2,681	76		COUNTERMEASURES SYSTEMS
2,617	42		ELECTRICAL POWER SUPPLY
2,369	46		FUEL SYSTEMS
2,268	44		LIGHTING SYSTEM
20,672	*		
76,620		1	
4,430	74		WEAPONS CONTROL SYSTEMS
1,606	14		FLIGHT CONTROLS
1,447	76		COUNTERMEASURES SYSTEMS
1,146	73		BOMBING NAVIGATION SYSTEMS
1,088	13		LANDING GEAR
984	27		TURBOFAN ENGINES
891	58		IN-FLIGHT TEST EQUIP SYS
784	57		INTEGR GUID/FLT CONT SYS
638	41		AIR CON/PRSRZ/ICE CONTROL
530	29		POWER PLANT INSTALLATION
4,490	*		
18,034		2	

94,654		TOTAL	

F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA
(OCT 1993-SEP 1994)

TOP 10 EMT BY SYSTEM

HOURS	BY WUC	ML	
23,627.6	14		FLIGHT CONTROLS
17,841.5	13		LANDING GEAR
15,594.2	74		WEAPONS CONTROL SYSTEMS
9,659.7	27		TURBOFAN ENGINES
7,6[illegible]9.1	75		WEAPON DELIVERY
7,5[illegible]8.2	46		FUEL SYSTEMS
6,508.7	41		AIR COND/PRSRZ/SURFACE ICE CONTROL
5,734.1	42		ELECTRICAL POWER SUPPLY
4,893.4	29		POWER PLANT INSTALLATION
3,979.4	76		COUNTERMEASURES SYSTEMS
135,441.6		1	
32,385.7	*		
36,790.4	74		WEAPONS CONTROL SYSTEMS
12,067.9	14		FLIGHT CONTROLS
11,750.4	76		COUNTERMEASURES SYSTEMS
10,934.1	73		BOMBING NAVIGATION SYSTEMS
5,608.4	42		ELECTRICAL POWER SUPPLY
5,431.8	57		INTEGRATED GUIDANCE/FLT CONT SYSTEMS
5,425.1	13		LANDING GEAR
4,798.7	58		IN-FLIGHT TEST EQUIPMENT SYSTEMS
3,742.3	27		TURBOFAN ENGINES
2,935.9	64		INTERPHONE SYSTEMS
22,413.0	*		
121,898.0		2	

257,339.6		TOTAL	

TOP 5 COMPONENT FAILURES

FAILURES	BY WUC	ML	
1,647	75E51		SUU63/A AIRCRAFT PYLON
1,624	751B6		LAU7/A GUIDED MISSILE LAUNCHER
1,526	13C11		MAIN LANDING GEAR MECH INSTALLATION
1,442	14211		AILERON INSTALLATION
1,283	754CD		BRU32/A ACFT BOMB EJECTOR RACK
69,098	*		
76,620		1	
631	742G6		AS3254/APG65 ANTENNA
560	742G1		T1377/APG65 RADAR TRANSMITTER
513	62X21		RT1250/ARC RADIO RECEIVER XMTR
500	742G2		R2089/APG65 RADAR RECEIVER EXCITER
464	57D91		CP1330/ASW44 ROLL-PITCH-YAW CMPTR
15,366	*		
18,034		2	

94,654		TOTAL	

F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 5 ML 1 COMPONENT FAILURES BY MALFUNCTION

FAILURES	BY MAL	WUC	
818	170		CORRODED
215	070		PUNCTD/RUPTURED/TORN/ BRKN/CUT/BURST
130	425		NICKED/CHIPPED
67	020		STRIPPED/WORN/CHAFED/ FRAYED
50	160		BROKEN WIRE/DEFEC/ CONTACT/CONNECTION
142	*		
1,422		751B6	LAU7/A GUIDED MISSILE LAUNCHER
1,008	170		CORRODED
116	070		PUNCTD/RUPTURED/ TORN/BRKN/CUT/BURST
84	425		NICKED/CHIPPED
47	190		CRACKED/CRAZED
36	020		STRIPPED/WORN/ CHAFED/FRAYED
108	*		
1,399		75E51	SUU63/A AIRCRAFT PYLON
899	170		CORRODED
38	932		DOES NOT ENGAGE/LOCK/ UNLOCK PROPERLY
34	160		BROKEN WIRE/DEFEC CONTACT/CONNECTION
31	020		STRIPPED/WORN/ CHAFED/FRAYED
30	127		ADJUSTMENT/ALIGNMENT IMPROPER
129	*		
1,161		754CD	BRU32/A ACFT BOMB EJECTOR RACK
54	170		CORRODED
15	070		PUNCTD/RUPTURED/ TORN/BRKN/CUT/BURST
9	190		CRACKED/CRAZED
9	425		NICKED/CHIPPED
7	020		STRIPPED/WORN/ CHAFED/FRAYED
25	*		
119		14211	AILERON INSTALLATION

63	170		CORRODED
9	425		NICKED/CHIPPED
6	020		STRIPPED/WORN/ CHAFED/FRAYED
6	070		PUNCTD/RUPTURED/ TORN/BRKN/CUT/BURST
2	128		RIGGING/INDEXING INCORRECT
14	*		
100		13C11	MAIN LANDING GEAR MECH INSTALLATION

4,201		TOTAL	

EMT FOR TOP 5 ML 1 COMPONENT FAILURES

HOURS		BY WUC	
1,663.1		75E51	SUU63/A AIRCRAFT PYLON
1,405.4		751B6	LAU7/A GUIDED MISSILE LAUNCHER
898.6		754CD	BRU32/A ACFT BOMB EJECTOR RACK
317.7		14211	AILERON INSTALLATION
159.3		13C11	MAIN LANDING GEAR MECH INSTALLATION

4,444.1	TOTAL		

F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

MMH FOR VERIFIED ML 1 FAILURES

HOURS	BY WUC	
14,324.9	75	WEAPON DELIVERY
47,839.0	14	FLIGHT CONTROLS
35,641.9	13	LANDING GEAR

97,805.8	TOTAL	

MMH FOR TOP 5 ML 1 COMPONENT FAILURES

HOURS		BY WUC	
3,082.6		75E51	SUU63/A AIRCRAFT PYLON
2,445.9		751B6	LAU7/A GUIDED MISSILE LAUNCHER
1,761.6		754CD	BRU32/A ACFT BOMB EJECTOR RACK
587.0		14211	AILERON INSTALLATION
251.4		13C11	MAIN LANDING GEAR MECH INSTALLATION

8,128.5	TOTAL		

F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 5 ML 2 COMPONENT FAILURES BY MALFUNCTION

FAILURES	BY MAL WUC	
258	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
229	127	ADJUSTMENT/ALIGNMENT IMPROPER
58	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
17	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
8	804	NO DEFECT-REM/INST FOR SCHED MAINT
25	*	
595	742G6	AS3254/APG65 ANTENNA
242	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
229	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
18	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
15	169	VOLTAGE INCORRECT
10	374	INTERNAL FAILURE
36	*	
550	742G1	T1377/APG65 RADAR TRANSMITTER
309	127	ADJUSTMENT/ALIGNMENT IMPROPER
175	255	NO OUTPUT
8	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
3	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
3	169	VOLTAGE INCORRECT
15	*	
513	62X21	RT1250/ARC RADIO RECEIVER XMTR
163	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
158	127	ADJUSTMENT/ALIGNMENT IMPROPER
150	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
9	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
5	169	VOLTAGE INCORRECT
13	*	
498	742G2	R2089/APG65 RADAR RECEIVER EXCITER
275	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
136	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
10	127	ADJUSTMENT/ALIGNMENT IMPROPER
7	169	VOLTAGE INCORRECT
6	447	WRONG LOGIC-PROGRAM/COMPUTER
27	*	
461	57D91	CP1330/ASW44 ROLL-PITCH-YAW CMPTR

2,617	TOTAL	

EMT FOR TOP 5 ML 2 COMPONENT FAILURES

HOURS	BY WUC	
5,474.8	742G1	T1377/APG65 RADAR TRANSMITTER
5,300.9	742G2	R2089/APG65 RADAR RECEIVER EXCITER
3,833.1	742G6	AS3254/APG65 ANTENNA
3,051.3	57D91	CP1330/ASW44 ROLL-PITCH-YAW CMPTR
2,483.9	62X21	RT1250/ARC RADIO RECEIVER XMTR

20,144.0	TOTAL	

F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

MMH FOR VERIFIED ML 2 FAILURES

HOURS	BY WUC	
69,209.2	74	WEAPONS CONTROL SYSTEMS
4,924.5	62	VHF COMM SYSTEMS
9,669.9	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS

83,803.6	TOTAL	

MMH FOR TOP 5 ML 2 COMPONENT FAILURES

HOURS	BY WUC	
11,493.5	742G1	T1377/APG65 RADAR TRANSMITTER
10,579.8	742G2	R2089/APG65 RADAR RECEIVER EXCITER
7,898.7	742G6	AS3254/APG65 ANTENNA
5,570.3	57D91	CP1330/ASW44 ROLL-PITCH-YAW CMPTR
4,819.9	62X21	RT1250/ARC RADIO RECEIVER XMTR

40,362.2	TOTAL	

TOP 10 NMCS COMPONENTS

HOURS	BY BEST-WUC	
103,943.2	27400	F404-GE-ENGINE
77,267.9	14513	LEADING EDGE FLAP DRIVE INSTL
74,650.0	742G6	AS3254/APG65 ANTENNA
66,991.5	14211	AILERON INSTALLATION
56,427.8	14612	TRAILING EDGE FLAP CONTROL
46,520.7	742G1	T1377/APG65 RADAR TRANSMITTER
46,401.9	14312	STABILIZER CONTROL INSTALLATION
36,409.5	57D91	CP1330/ASW44 ROLL-PITCH-YAW CMPTR
35,065.7	14412	RUDDER CONTROL
34,937.1	58X17	ID2389/A INTEG FUEL-ENGINE IND
1,517,638.7	*	

2,096,254.0	TOTAL	

TOP 10 NMCM COMPONENTS

HOURS	BY BEST-WUC	
107,481.8	27400	F404-GE-ENGINE
97,296.5	57D91	CP1330/ASW44 ROLL-PITCH-YAW CMPTR
96,326.3	14513	LEADING EDGE FLAP DRIVE INSTL
80,775.1	14612	TRAILING EDGE FLAP CONTROL
80,164.9	29123	STARTER INSTALLATION
70,646.6	42118	GENERATOR CONVERTOR UNIT
69,246.6	14312	STABILIZER CONTROL INSTALLATION
61,663.0	46115	FUEL FEED SYSTEM
57,240.4	14412	RUDDER CONTROL
51,353.8	13C11	MAIN LANDING GEAR MECH INSTALLATION
2,573,418.4	*	

3,345,613.4	TOTAL	

F/A-18C *HORNET* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 5 A799 MMH/SYSTEMS

HOURS	BY WUC ML	
6,490.7	74	WEAPONS CONTROL SYSTEMS
2,092.5	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS
2,040.6	14	FLIGHT CONTROLS
1,749.3	27	TURBOFAN ENGINES
1,710.5	13	LANDING GEAR
11,166.4	*	
25,250.0	1	
8,303.0	74	WEAPONS CONTROL SYSTEMS
3,239.6	73	BOMBING NAVIGATION SYSTEMS
2,063.8	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS
1,489.6	58	IN-FLIGHT TEST EQUIPMENT SYSTEMS
1,014.6	75	WEAPON DELIVERY
8,002.4	*	
24,113.0	2	

49,363.0	TOTAL	

E-2C *HAWKEYE* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 10 SYSTEM FAILURES

FAILURES	BY WUC	
	ML	
6,888	72	RADAR NAVIGATION SYSTEMS
4,427	44	LIGHTING SYSTEMS
3,756	29	POWER PLANT INSTALLATION
3,368	13	ALIGHTING/LAUNCHING SYSTEM
2,981	14	DIRECTIONAL FLT CONTROLS/LIFT SYSTEM
2,703	41	ENVIRONMENTAL CONTROLS/PNEUMATIC SYS
2,681	42	ELEC PWR SPLY/DISTRIBUTION/LTG SYS
2,106	32	HYDRAULIC PROPELLERS
1,788	12	FURNISHINGS/COMPARTMENTS
1,724	22	TURBOSHAFT ENGINES
17,023	*	
49,445	1	
4,167	72	RADAR NAVIGATION SYSTEMS
846	73	BOMBING NAVIGATION SYSTEMS
789	56	FLIGHT REFERENCE SYSTEMS
463	61	HF COMMUNICATIONS SYSTEMS
446	13	ALIGHTING/LAUNCHING SYSTEMS
443	64	INTERPHONE SYSTEMS
437	29	POWER PLANT INSTALLATION
427	51	INSTRUMENTATION SYSTEMS
414	41	ENVIRONMENTAL CONTROLS/PNEUMATIC SYS
392	22	TURBOSHAFT ENGINES
3,091	*	
11,915	2	

61,360	TOTAL	

E-2C *HAWKEYE* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 10 EMT BY SYSTEM

HOURS	BY WUC ML	
18,750.3	72	RADAR NAVIGATION SYSTEMS
10,110.1	14	DIRECTIONAL FLT CONTROLS/LIFT SYSTEM
8,431.2	29	POWER PLANT INSTALLATION
8,093.3	42	ELEC PWR SPLY/DISTRIBUTION/LTG SYSTEM
7,898.4	32	HYDRAULIC PROPELLERS
7,704.0	41	ENVIRONMENTAL CONTROLS/PNEUMATIC SYS
6,876.3	13	ALIGHTING/LAUNCHING SYSTEM
5,251.3	22	TURBOSHAFT ENGINES
4,837.0	44	LIGHTING SYSTEMS
3,615.2	56	FLIGHT REFERENCE SYSTEMS
33,491.0	*	
115,058.1	1	
35,707.0	72	RADAR NAVIGATION SYSTEMS
11,637.5	73	BOMBING NAVIGATION SYSTEMS
4,117.8	61	HF COMMUNICATIONS SYSTEMS
3,785.2	76	COUNTERMEASURES SYSTEMS
3,091.4	56	FLIGHT REFERENCE SYSTEMS
3,048.5	29	POWER PLANT INSTALLATION
2,576.2	65	IFF SYSTEMS
2,476.1	51	INSTRUMENTATION SYSTEMS
2,442.8	64	INTERPHONE SYSTEMS
2,432.0	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS)
17,311.0	*	
88,625.5	2	

203,683.6	TOTAL	

TOP 5 COMPONENT FAILURES

FAILURES	BY WUC		
		ML	
1,331	4422K		UTILITY LIGHT
901	32512		VARIABLE PITCH PROPELLER
645	14121		RUDDER
621	29E10		POWER PLANT SYSTEM INSTL/ENGINE ASSY
599	32513		PROPELLER CONTROL ASSEMBLY
45,348	*		
49,445		1	
524	726J4		IP1040/APA172 AZ RANGE IND (CONTD)
294	726J2		IP1040/APA172 AZ RANGE INDICATOR
291	728E1		CP1084/ASQ DGTL DATA CMPTR 46A1
273	728E2		CV2868/ASQ DIGITAL DATA CONV 46A2
263	64184		C2645/AIC14 ICS CONTROL
10,270	*		
11,915		2	

61,360		TOTAL	

E-2C *HAWKEYE* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 5 ML 1 COMPONENT FAILURES BY MALFUNCTION

FAILURES	BY MAL WUC	
1,060	080	BURNED OUT (LIGHT BULBS/FUSES)
100	160	BROKEN WIRE/DEFECTIVE/CONNECTION
76	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
31	170	CORRODED
13	374	INTERNAL FAILURE
51	*	
1,331	4422K	UTILITY LIGHT
241	170	CORRODED
70	127	ADJUSTMENT/ALIGNMENT IMPROPER
70	306	CONTAMINATION (NON-METALLIC)
68	020	STRIPPED/WORN/CHAFED/FRAYED
36	381	LEAKING-INTERNAL/EXTERNAL
136	*	
621	29E10	POWER PLANT SYS INSTL/ENGINE ASSY
67	170	CORRODED
62	020	STRIPPED/WORN/CHAFED/FRAYED
44	117	DETERIORATED/ERODED
44	127	ADJUSTMENT/ALIGNMENT IMPROPER
40	458	OUT OF BALANCE
140	*	
397	32512	VARIABLE PITCH PROPELLER
95	170	CORRODED
40	020	STRIPPED/WORN/CHAFED/FRAYED
32	190	CRACKED/CRAZED
32	425	NICKED/CHIPPED
19	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
58	*	
276	14121	RUDDER
14	170	CORRODED
8	381	LEAKING-INTERNAL/EXTERNAL
5	070	PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
4	037	FLUCTUATES/OSCILLATES
3	127	ADJUSTMENT/ALIGNMENT IMPROPER
15	*	
49	32513	PROPELLER CONTROL ASSEMBLY

2,674	TOTAL	

EMT FOR TOP 5 ML 1 COMPONENT FAILURES

HOURS	BY WUC	
1,939.4	32512	VARIABLE PITCH PROPELLER
1,186.4	29E10	POWER PLANT SYSTEM INSTL/ENGINE ASSY
1,083.0	4422K	UTILITY LIGHT
706.4	14121	RUDDER
206.6	32513	PROPELLER CONTROL ASSEMBLY

5,121.8	TOTAL	

E-2C *HAWKEYE* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

MMH FOR VERIFIED ML 1 FAILURES

HOURS	BY WUC	
18,502.7	32	HYDRAULIC PROPELLERS
16,748.9	29	POWER PLANT INSTALLATION
7,644.8	44	LIGHTING SYSTEMS
20,030.8	14	DIRECTIONAL FLT CONTROLS/LIFT SYSTEM

62,927.2	TOTAL	

MMH FOR TOP 5 ML 1 COMPONENT FAILURES

HOURS	BY WUC	
4,808.3	32512	VARIABLE PITCH PROPELLER
2,716.0	29E10	POWER PLANT SYSTEM INSTL/ENGINE ASSY
1,639.1	4422K	UTILITY LIGHT
1,298.7	14121	RUDDER
510.7	32513	PROPELLER CONTROL ASSEMBLY

10,972.8	TOTAL	

TOP 5 ML 2 COMPONENT FAILURES BY MALFUNCTION

FAILURES	BY MAL	WUC	
102	127		ADJUSTMENT/ALIGNMENT IMPROPER
85	160		BROKEN WIRE/DEFEC/CONTACT/CONNECTION
75	290		FAILS DIAGNOSTIC/AUTOMATIC TESTS
15	070		PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
4	374		INTERNAL FAILURE
13	*		
294		726J2	IP1040/APA172 AZ RANGE INDICATOR
77	255		NO OUTPUT
63	070		PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
57	160		BROKEN WIRE/DEFEC CONTACT/CONNECTION
31	127		ADJUSTMENT/ALIGNMENT IMPROPER
10	374		INTERNAL FAILURE
25	*		
263		64184	C2645/AIC14 ICS CONTROL
15	070		PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
12	160		BROKEN WIRE/DEFEC CONTACT/CONNECTION
7	127		ADJUSTMENT/ALIGNMENT IMPROPER
2	135		STRUCK/BINDING/JAMMED
2	290		FAILS DIAGNOSTIC/AUTOMATIC TESTS
6	*		
44		726J4	IP1040/APA172 AZ RANGE IND (CONTD)

7	070		PUNCTD/RUPTURED/TORN/BRKN/CUT/BURST
1	160		BROKEN WIRE/DEFEC CONTACT/CONNECTION
1	374		INTERNAL FAILURE
9		728E1	CP1084/ASQ DGTL DATA CMPTR 46A1
1	127		ADJUSTMENT/ALIGNMENT IMPROPER
1		728E2	CV2868/ASQ DIGITAL DATA CONV 46A2

611		TOTAL	

E-2C *HAWKEYE* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

EMT FOR TOP 5 ML 2 COMPONENT FAILURES

HOURS	BY WUC	
3,941.1	726J2	IP1040/APA172 AZ RANGE INDICATOR
1,437.6	64184	C2645/AIC14 ICS CONTROL
157.2	726J4	IP1040/APA172 AZ RANGE IND (CONTD)
17.0	728E2	CV2868/ASQ DIGITAL DATA CONV 46A2
1.8	728E1	CP1084/ASQ DGTL DATA CMPTR 46A1

5,554.7	TOTAL	

MMH FOR VERIFIED ML 2 FAILURES

HOURS	BY WUC	
64,381.5	72	RADAR NAVIGATION SYSTEMS
4,256.8	65	INTERPHONE SYSTEMS

68,638.3	TOTAL	

MMH FOR TOP 5 ML 2 COMPONENT FAILURES

HOURS	BY WUC	
7,160.5	726J2	IP1040/APA172 AZ RANGE INDICATOR
2,491.9	64184	C2645/AIC14 ICS CONTROL
202.2	726J4	IP1040/APA172 AZ RANGE IND (CONTD)
17.0	728E2	CV2868/ASQ DIGITAL DATA CONV 46A2
3.6	728E1	CP1084/ASQ DGTL DATA CMPTR 46A1

9,875.2	TOTAL	

TOP 10 NMCS COMPONENTS

HOURS	BY BEST-WUC	
21,144.1	1441B	FEEL SPRING PUSHROD
20,922.8	14121	RUDDER
14,750.0	728E1	CP1084/ASQ DGTL DATA CMPTR 46A1
14,258.1	1451A	BUNGEE
11,841.8	62X2K	F1556 BANDPASS FILTER
11,244.0	728E2	CV2868/ASQ DIGITAL DATA CONV 46A2
9,692.8	726DW	AM6412/APS120 RF AMPLIFIER
8,435.6	32513	PROPELLER CONTROL ASSEMBLY
7,789.4	726T3	O1720/APS125 PULSE GENERATOR
7,588.7	14521	ELEVATOR TANDEM ACTUATOR
633,731.1	*	

761,398.4	TOTAL	

E-2C *HAWKEYE* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 10 NMCM COMPONENTS

HOURS	BY BEST-WUC	
120,731.2	14121	RUDDER
57,421.8	223D1	FUEL SYSTEM ASSEMBLY
45,216.9	29E11	ENGINE ACCESSORIES INSTALLATION
44,834.4	32513	PROPELLER CONTROL ASSEMBLY
38,775.2	29E1B	ENGINE OIL COOLER INSTALLATION
37,869.1	14141	LANDING FLAPS
36,242.6	14131	ELEVATOR
27,804.1	45111	VARIABLE DISPLACEMENT PUMP 3000 P
25,705.3	14521	ELEVATOR TANDEM ACTUATOR
23,549.5	4512Q	HYDRAULIC HOSE/TUBING
1,553,793.4	*	

2,011,943.5	TOTAL	

TOP 5 A799 MMH/SYSTEMS

HOURS	BY WUC	
	ML	
2,415.8	72	RADAR NAVIGATION SYSTEMS
1,274.4	42	ELEC PWR SPLY/DISTR/LTG SYSTEMS
727.4	14	DIRECTIONAL FLT CONT/LIFT SYSTEM
724.8	41	ENVIRON CONTROLS/PNEUMATIC SYS
637.6	29	POWER PLANT INSTALLATION
6,048.7	*	
11,828.7	1	
5,129.3	72	RADAR NAVIGATION SYSTEMS
1,960.4	73	BOMBING NAVIGATION SYSTEMS
789.7	61	HF COMM SYSTEMS
674.8	56	FLIGHT REFERENCE SYSTEMS
669.2	64	INTERPHONE SYSTEMS
4,261.2	*	
13,484.6	2	

25,313.3	TOTAL	

S-3B *VIKING* SELECTED WEAPONS SYSTEMS DATA (OCT 1993-SEP 1994)

TOP 10 SYSTEM FAILURES

COUNT	BY WUC ML	
8,762	73	BOMBING NAVIGATION SYSTEMS
6,988	14	FLIGHT CONTROLS
6,978	13	LANDING GEAR
6,659	42	ELECTRICAL POWER SYSTEM
4,926	29	POWER PLANT INSTALLATION
4,248	44	LIGHTING SYSTEM
3,417	27	TURBOFAN ENGINES
2,867	41	AIR CON/PRSRZ/ICE CONTROL
2,720	72	RADAR NAVIGATION SYSTEMS
2,691	64	INTERPHONE SYSTEMS
20,872	*	
71,128	1	
5,098	73	BOMBING NAVIGATION SYSTEMS
1,247	13	LANDING GEAR
1,126	64	INTERPHONE SYSTEMS
1,124	72	RADAR NAVIGATION SYSTEMS
1,074	14	FLIGHT CONTROLS
967	57	INTGRTD GDNCE/FLT CONT SYS
820	71	RADIO NAVIGATION SYSTEMS
743	29	POWER PLANT INSTALLATION
627	42	ELECTRICAL POWER SYSTEM
593	27	TURBOFAN ENGINES
5,237	*	
18,656	2	

89,784	TOTAL	

TOP 10 EMT BY SYSTEM

SUM	BY WUC ML	
19,262.7	14	FLIGHT CONTROLS
16,094.7	73	BOMBING NAVIGATION SYSTEMS
13,779.8	42	ELECTRICAL POWER SYSTEM
11,031.2	13	LANDING GEAR
7,979.2	29	POWER PLANT INSTALLATION
7,854.6	27	TURBOFAN ENGINES
5,083.8	41	AIR CONDITIONING/PRSRZ/ICE CONTROL
4,949.0	44	LIGHTING SYSTEM
4,573.5	72	RADAR NAVIGATION SYSTEMS
4,096.0	46	FUEL SYSTEM
33,270.8	*	
127,975.3	1	
40,708.1	73	BOMBING NAVIGATION SYSTEMS
9,086.6	64	INTERPHONE SYSTEMS
8,691.8	72	RADAR NAVIGATION SYSTEMS
7,717.5	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS
5,831.8	77	PHOTOGRAPHIC/RECONNAISSANCE SYSTEMS
5,639.9	71	RADIO NAVIGATION SYSTEMS
4,799.8	13	LANDING GEAR
4,636.7	14	FLIGHT CONTROLS
4,407.2	65	IFF SYSTEMS
4,143.4	63	UHF COMMUNICATIONS
24,825.3	*	
120,488.1	2	

248,463.4	TOTAL	

TOP 5 COMPONENT FAILURES

COUNT	BY WUC	ML	
1,492	29Q4H		ENG PYLON INST/ASSY
1,180	57367		CP1074/ASW33 FLT DATA COMPUTER
947	64351		LS601/AI INTERCOMMUNICATION STATION
914	64354		CV3048/AI CONV INTERCONNECT BOX
810	754BQ		BRU14 BOMB RACK ASSEMBLY
65,785	*		
71,128		1	

709	13A6K	WHL/TIRE ASSY/BK ASSY/SHTL Y/DUAL FL
492	57367	CP1074/ASW33 FLT DATA COMPUTER
452	73B62	CV2745/ASA84 NAV DATA CONVERTER
450	63271	RT1017/ARC156 RADIO RCVR-XMTR
430	64354	CV3048/AI CONV INTERCONNECT BOX
16,123	*	
18,656	2	

89,784	TOTAL	

TOP 5 ML 1 COMPONENT FAILURES BY MALFUNCTION

COUNT	BY MAL WUC	
559	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
297	374	INTERNAL FAILURE
128	127	ADJUSTMENT/ALIGNMENT IMPROPER
55	070	PUNC/RUPTURED/TORN/BRKN/CUT/BURST
29	255	NO OUTPUT
87	*	
1,155	57367	CP1074/ASW33 FLT DATA COMPUTER
310	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
242	080	BURNED OUT (LIGHT BULBS/FUSES)
80	255	NO OUTPUT
77	374	INTERNAL FAILURE
44	070	PUNC/RUPTURED/TORN/BRKN/CUT/BURST
186	*	
939	64351	LS601/AI INTERCOMMUNICATION STATION
470	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
138	255	NO OUTPUT
82	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
79	374	INTERNAL FAILURE
44	170	CORRODED
97	*	
910	64354	CV3048/AI CONV INTERCONNECT BOX
620	170	CORRODED
68	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
26	070	PUNC/RUPTURED/TORN/BRKN/CUT/BURST
22	127	ADJUSTMENT/ALIGNMENT IMPROPER
9	020	STRIPPED/WORN/CHAFED/FRAYED
37	*	
782	754BQ	BRU14 BOMB RACK ASSEMBLY

113	170	CORRODED
18	070	PUNC/RUPTURED/TORN/BRKN/CUT/BURST
17	429	PEELED/BLISTERED
8	020	STRIPPED/WORN/CHAFED/FRAYED
8	190	CRACKED/CRAZED
30	*	
194	29Q4H	ENGINE WING PYLON INSTALLATION/ASSY

3,980	TOTAL	

EMT FOR TOP 5 ML 1 COMPONENT FAILURES

SUM	BY WUC	
1,582.4	57367	CP1074/ASW33 FLT DATA COMPUTER
1,401.5	64354	CV3048/AI CONV INTERCONNECT BOX
1,132.3	64351	LS601/AI INTERCOMMUNICATION STATION
706.3	754BQ	BRU14 BOMB RACK ASSEMBLY
301.3	29Q4H	ENGINE WING PYLON INSTALLATION/ASSY

5,123.8	TOTAL	

MMH FOR VERIFIED ML 1 FAILURES

SUM	BY WUC	
5,781.1	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS
6,227.6	64	INTERPHONE SYSTEMS
2,259.7	75	WEAPON DELIVERY

14,368.4	TOTAL	

MMH FOR TOP 5 ML 1 COMPONENT FAILURES

SUM	BY WUC	
2,697.0	57367	CP1074/ASW33 FLT DATA COMPUTER
2,489.4	64354	CV3048/AI CONV INTERCONNECT BOX
1,879.4	64351	LS601/AI INTERCOMMUNICATION STATION
877.2	754BQ	BRU14 BOMB RACK ASSEMBLY
425.8	29Q4H	ENGINE WING PYLON INSTALLATION/ASSY

8,368.8	TOTAL	

TOP 5 ML 2 COMPONENT FAILURES BY MALFUNCTION

COUNT	BY MAL WUC	
283	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
151	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
35	070	PUNC/RUPTURED/TORN/BROKEN/CUT/BURST
4	374	INTERNAL FAILURE
3	127	ADJUSTMENT/ALIGNMENT IMPROPER
10	*	
486	57367	CP1074/ASW33 FLT DATA COMPUTER
272	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
141	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
15	070	PUNCT/RUPTURED/TORN/BROKEN/CUT/BURST
14	127	ADJUSTMENT/ALIGNMENT IMPROPER
2	374	INTERNAL FAILURE
7	*	
451	73B62	CV2745/ASA84 NAV DATA CONVERTER
149	127	ADJUSTMENT/ALIGNMENT IMPROPER
119	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
116	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
33	070	PUNCT/RUPTURED/TORN/BROKEN/CUT/BURST
12	170	CORRODED
18	*	
447	63271	RT1017/ARC156 RADIO RCVR-XMTR
240	160	BROKEN WIRE/DEFEC CONTACT/CONNECTION
102	290	FAILS DIAGNOSTIC/AUTOMATIC TESTS
43	127	ADJUSTMENT/ALIGNMENT IMPROPER
27	070	PUNCT/RUPTURED/TORN/BROKEN/CUT/BURST
10	374	INTERNAL FAILURE
6	*	
428	64354	CV3048/AI CONV INTERCONNECT BOX
6	572	EDDY-CURRENT INSPECTION
4	020	STRIPPED/WORN/CHAFED/FRAYED
4	781	TIRE LEAKAGE EXCESSIVE OR BLOWOUT
3	070	PUNCT/RUPTURED/TORN/BROKEN/CUT/BURST
3	571	MAGNETIC PARTICLE INSPECTION
9	*	
29	13A6K	WHL/TIRE ASSY/BK ASSY/SHTLY/DUAL FL

1,841	TOTAL	

EMT FOR TOP 5 ML 2 COMPONENT FAILURES

SUM	BY WUC	
5,528.3	57367	CP1074/ASW33 FLT DATA COMPUTER
4,442.7	64354	CV3048/AI CONV INTERCONNECT BOX
4,125.3	73B62	CV2745/ASA84 NAV DATA CONVERTER
3,454.0	63271	RT1017/ARC156 RADIO RCVR-XMTR
91.1	13A6K	WHL/TIRE ASSY/BK ASSY/SHTL Y/DUAL FL

17,641.4	TOTAL	

MMH FOR VERIFIED ML 2 FAILURES

SUM	BY WUC	
11,981.8	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS
13,413.4	64	INTERPHONE SYSTEMS
66,753.3	73	BOMBING NAVIGATION SYSTEMS
6,435.7	63	UHF COMM SYSTEMS
8,037.4	13	LANDING GEAR

106,621.6	TOTAL	

MMH FOR TOP 5 ML 2 COMPONENT FAILURES

SUM	BY WUC	
8,498.2	57367	CP1074/ASW33 FLT DATA COMPUTER
6,565.6	64354	CV3048/AI CONV INTERCONNECT BOX
6,292.7	73B62	CV2745/ASA84 NAV DATA CONVERTER
5,487.8	63271	RT1017/ARC156 RADIO RCVR-XMTR
191.2	13A6K	WHL/TIRE ASSY/BK ASSY/SHTL Y/DUAL FL

27,035.5	TOTAL	

TOP 10 NMCS COMPONENTS

SUM	BY BEST-WUC	
103,468.4	722H1	RT1023/APN201 RDR RCVR TRANSMITTE
23,839.7	14125	COMPLETE ELEVATOR ASSEMBLY
21,696.7	726R7	AS3637/APS137(V) ANTENNA
21,253.8	73B43	IP1054/ASA82 TAC ACOUSTIC INDICAT
20,860.2	29Q4Q	AIR START VALVE
20,583.4	722H2	ID1770/APN201 HEIGHT INDICATOR
20,473.7	24A22	GTCP36-201 GAS TURBINE ENGINE
19,966.0	13A71	HYDR PLMB INSTL RH WHL WELL FS 415-4
19,557.9	727H3	T1203/APS116 RADAR SET TRANSMITTE
17,451.6	726RG	R2308/APS137(V) RCVR-PULSE CMPSR
1,400,327.9	*	

1,689,479.3	TOTAL	

TOP 10 NMCM COMPONENTS

SUM	BY BEST-WUC	
92,746.4	14125	COMPLETE ELEVATOR ASSEMBLY
55,440.3	42111	INTEGRATED DRIVE GENERATOR ASSEMBLY
50,899.3	12111	EJECTION SEAT ASSEMBLY IE-1
47,609.1	27100	TF34 ENGINE
47,405.5	24A22	GTCP36-201 GAS TURBINE ENGINE
46,607.9	29Q4Q	AIR START VALVE
41,156.2	1431C	AIL/ROLL TRIM/SPBK/ROLL MIXER SERVO
37,665.8	14325	INNER WING LWR SPOILER NULL MECHANIS
34,348.9	13A6K	WHL/TIRE ASSY/BK ASSY/SHTL Y/DUAL FL
32,603.1	29Q4F	TURBOFAN ENGINE BUILDUP ASSEMBLY
2,934,329.4	*	

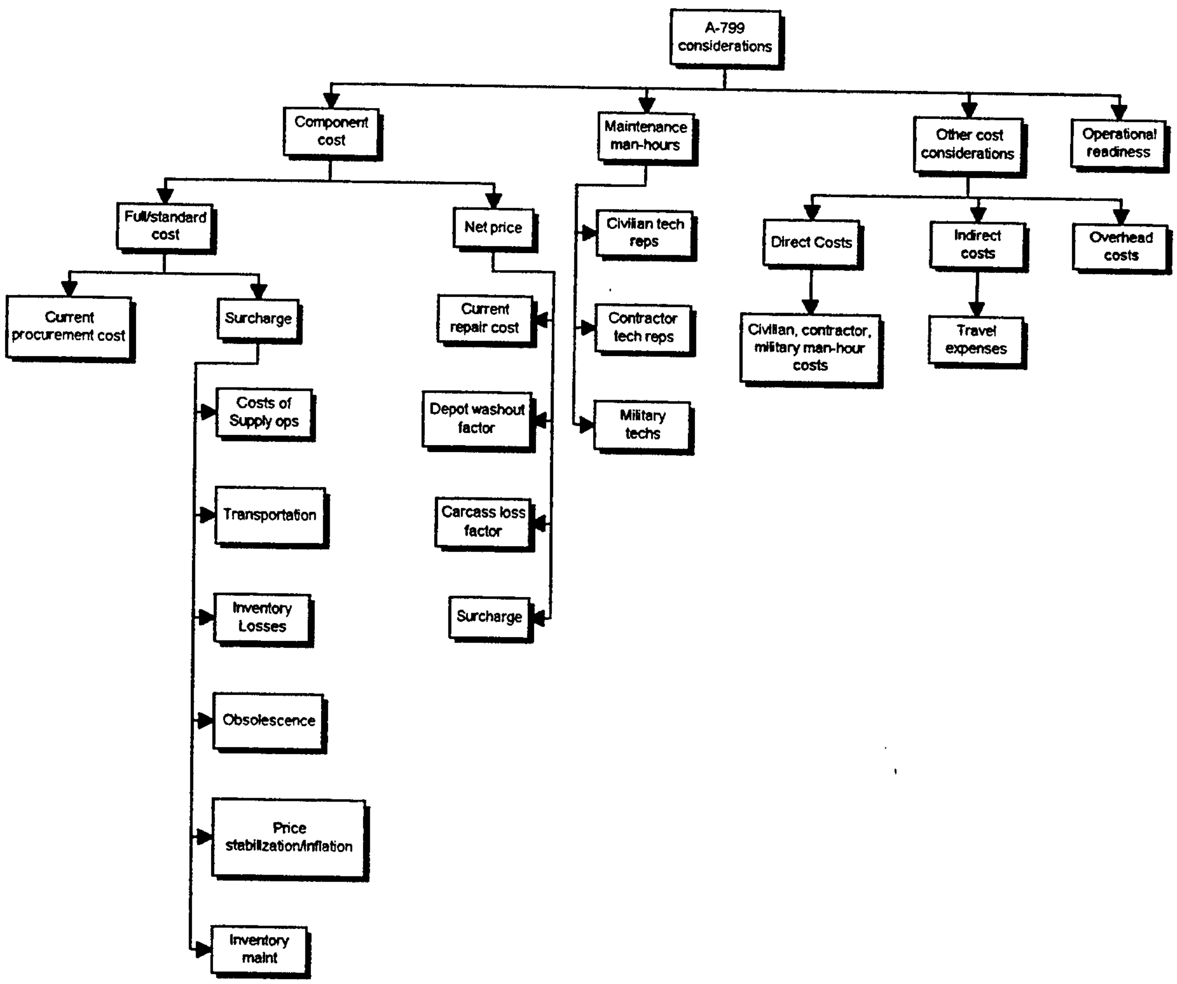
3,420,811.9	TOTAL	

TOP 5 A799 MMH/SYSTEMS

SUM	BY WUC ML	
2,636.1	73	BOMBING NAVIGATION SYSTEMS
820.3	14	FLIGHT CONTROLS
648.8	72	RADAR NAVIGATION SYSTEMS
637.9	13	LANDING GEAR
538.1	46	FUEL SYSTEM
5,226.3	*	
10,507.5	1	
6,274.3	73	BOMBING NAVIGATION SYSTEMS
1,349.4	57	INTEGRATED GUIDANCE/FLT CONT SYSTEMS
1,273.3	72	RADAR NAVIGATION SYSTEMS
1,193.9	64	INTERPHONE SYSTEMS
1,077.1	71	RADIO NAVIGATION SYSTEMS
6,111.2	*	
17,279.2	2	

27,786.7	TOTAL	

APPENDIX B. A-799



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